MIDDLE EAST TECHNICAL UNIVERSITY

Department of Electrical and Electronics Engineering

EE463 Project-3 Report

3-Phase Thyristor Rectifiers and DC/DC Converters

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Introduction

In this report, a 3-phase thyristor converter controlling a permanent magnet DC machine , a Buck converter and a DC-DC converter (Boost converter) topologies are investigated through Simulink. The AC source is assumed to be 400Vl-l and 50Hz.

Results

In this part of the report, schematics and their resultant graphs of above mentioned topologies are included. Later their design processes are detailed and the operations of each concept are explained.

Part 1 - Three Phase Thyristor Converter and Controlled Permanent Magnet DC Machine

In PI controller, using 2 as the proportionality constant, P resulted in an overshoot of approximately 8 rad/s in 3 second and after 9 seconds it settled to 150.8rad/s for the 150 rad/s reference speed case. Increasing P to the value of 10 reduced the overshoot to 0.8rad/s and hence that is what was used. For PI, settling time was the determining factor which was given by 1.5 as the its value.

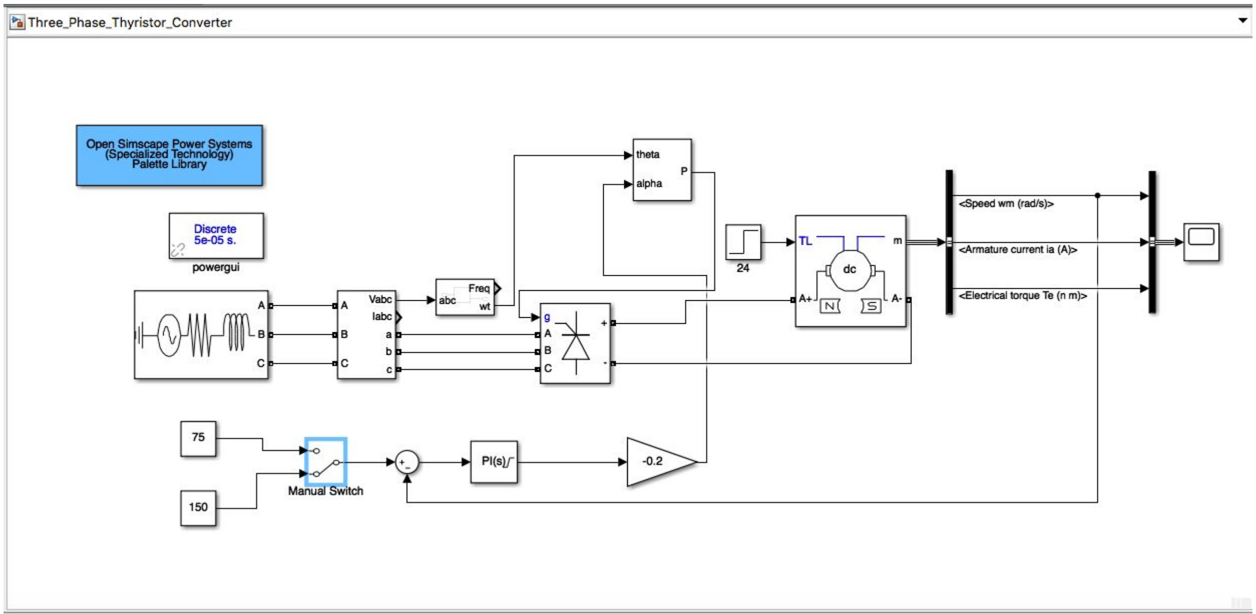

Figure 1: Schematics of the three phase thyristor converter topology controlling a permanent magnet DC machine.

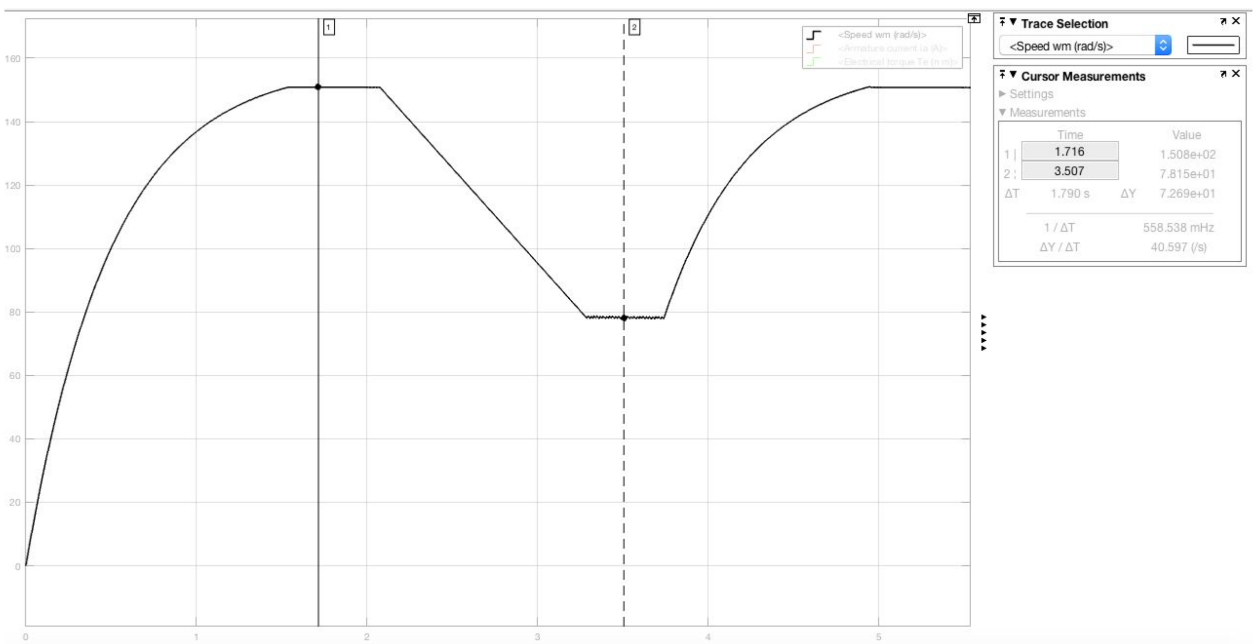

Figure 2: Graph of speed(rad/s) of the permanent magnet DC motor changing under the specified switching conditions where P is 10 and PI is 1.5.

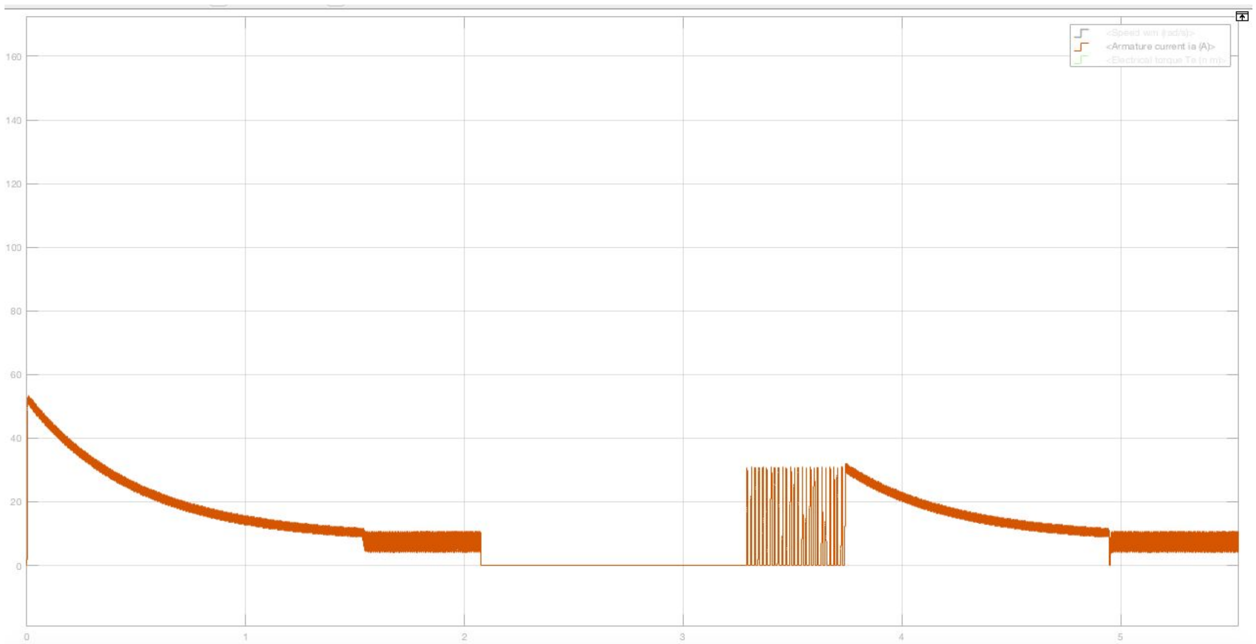

Figure 3: Graph of armature current (A) of the permanent magnet DC motor changing under the specified switching conditions where P is 10 and PI is 1.5.

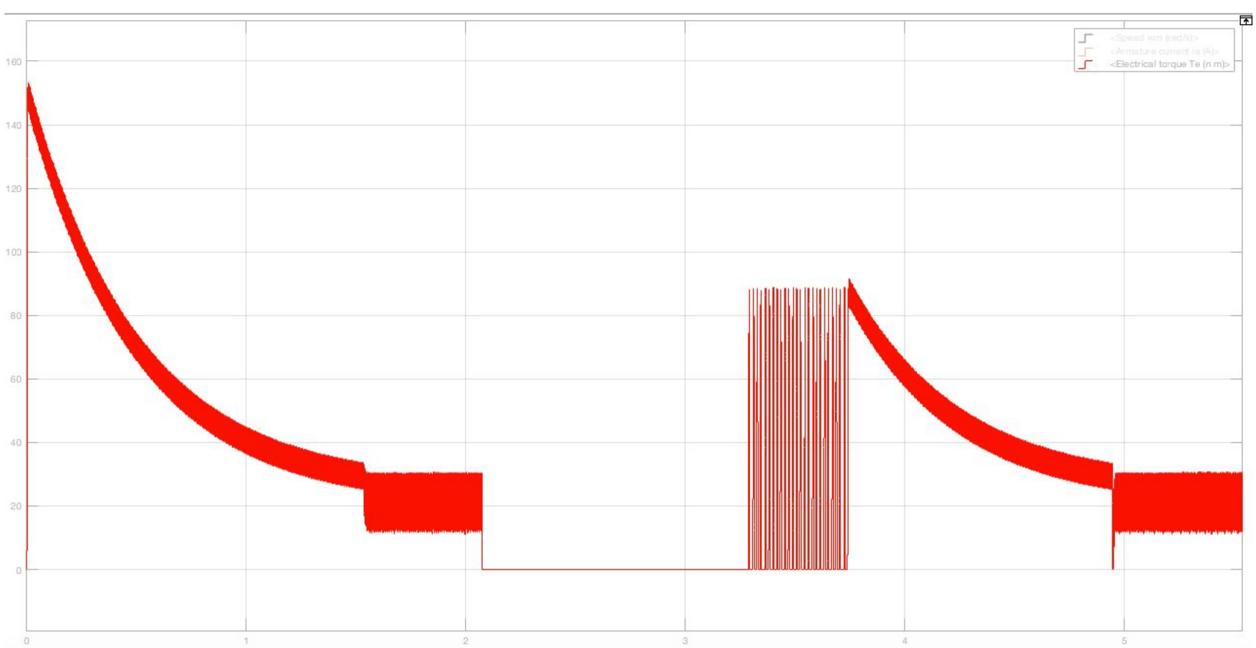

Figure 4: Graph of electrical torque (N.m) of the permanent magnet DC motor changing under the specified switching conditions where P is 10 and PI is 1.5.

From figure 3 and 4, it can be deduced that armature current and electrical torque has a direct relationship with one another. This is result of the following relationship: $T = I_a \, x \, k_t$ where k_t is the torque constant specific to the motor.

Part 2 - Buck Converter

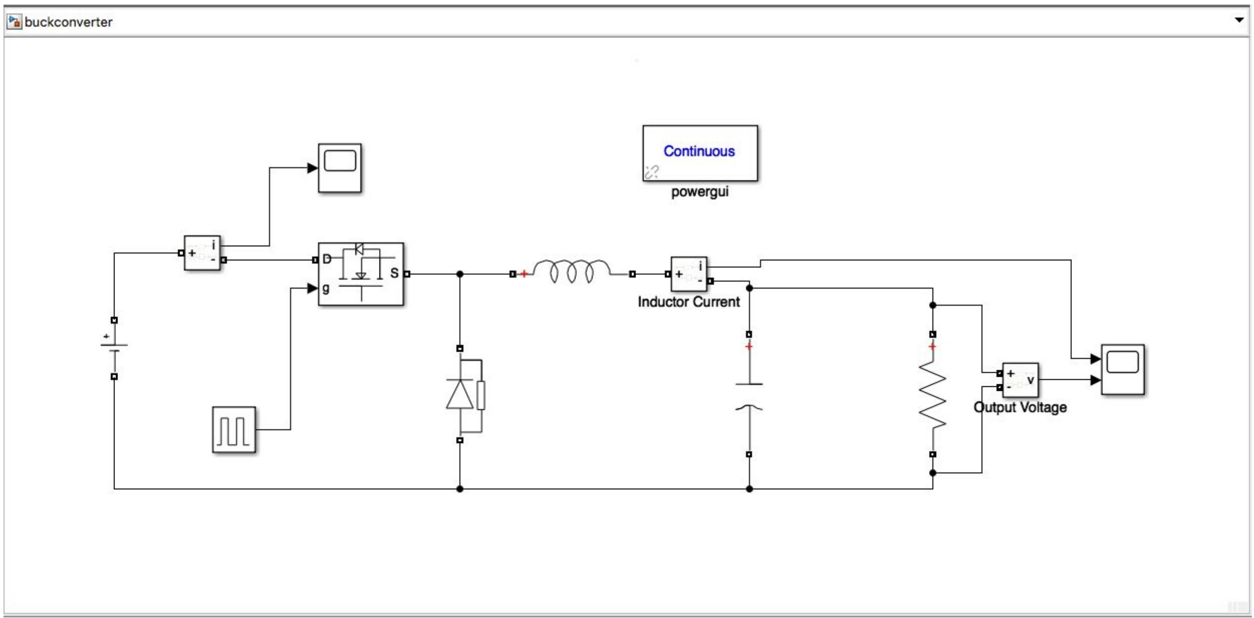

Figure 5: Schematics of the Buck converter topology.

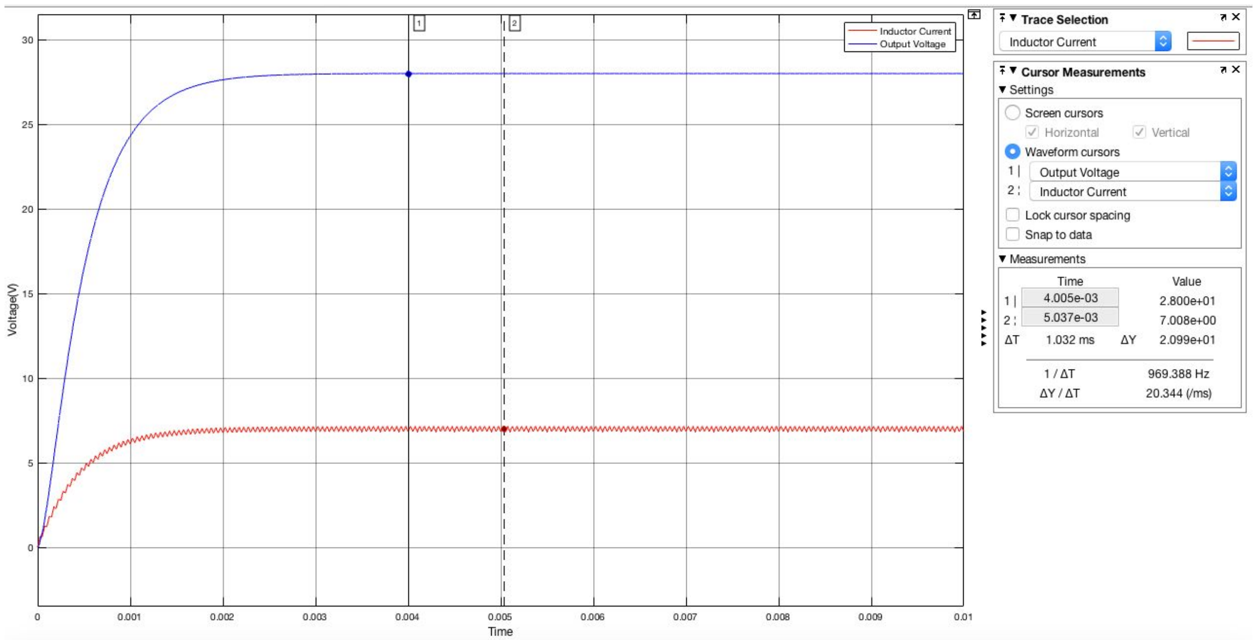

Figure 6: Graph of inductor current(A)(red) and output voltage(V)(blue)

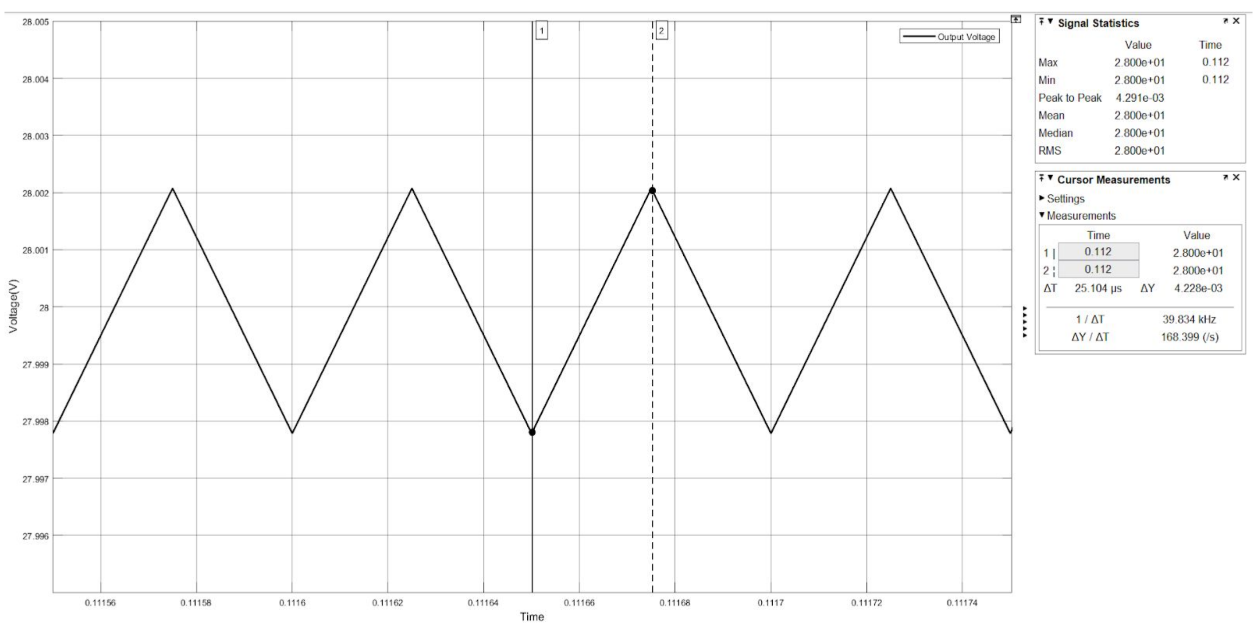

Figure 7: Graph of output voltage at steady state

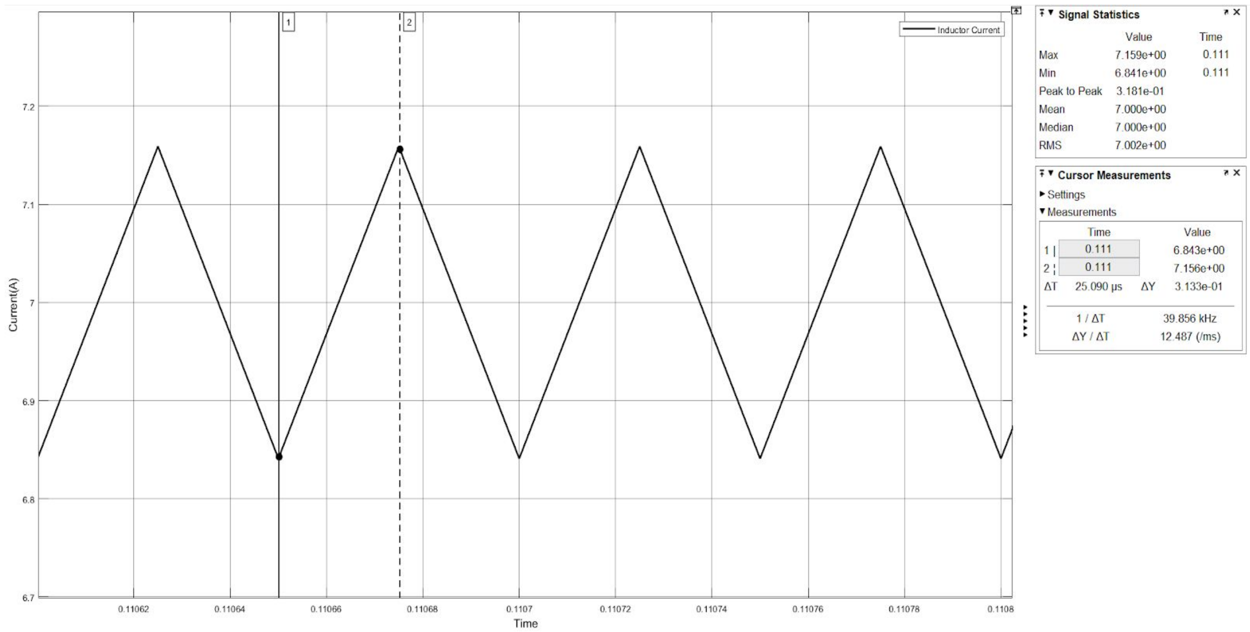

Figure 8:*Graph of* inductor current at steady state

2.1.Specifications

-Load (R) : 4 Ohm

-Input Voltage (V_{in}) : 56V

-Output Voltage (V_{out}) : 28V

-Switching Frequency (f_s) : 20kHz

-Inductor Current Ripple (ΔI_L) : 300mA

-Output Voltage Ripple (ΔV_{out}) : 90mV

$$\Delta V_{out} = \frac{T_s^2 \times V_{out} \times (1-D)}{8LC} \quad \text{where Ts : switching period and D: duty cycle} \quad (1)$$

$$\Delta I_L = \frac{T_s \, x \, V_{out} \times (1-D)}{L} \quad (2)$$

$$C = \frac{\Delta I_L}{8 \, x \, f_s \, x \, \Delta V_{out}} \quad (3)$$

$$L = \frac{(V_{in} - V_{out}) \times D}{\Delta I_L \, x \, f_s} \quad (4)$$

Firstly, 90 mV was stated as output voltage ripple and 300 mA was stated as inductor current ripple.Also,we selected switching frequency as 20 kHz. Then,we designed our buck converter circuit with respect to (1) and (2). Inductor and capacitor values are selected in our design:

L = 2.2 mH

C = 22 uF

In our simulation result, we expected output voltage ripple(ΔV_{out}) to be as nearly as 90 mV from (1) , but we obtained 4mV ripple voltage. For inductor current ripple (ΔI_L) , we expected 318 mA from (2) and in our simulation, we found nearly the same result.(ΔI_L = 313 mA).

Also, we designed buck converter using (3) and (4).Using these equations, we obtained the same results compared to previous one.

2.2.Circuit Elements

2.2.1 Inductor

Mouser Part No: [AISR-01-222J]

Manufacturer Part Number: AISR-01-222J

DC Resistance: 43 mOhms

Cost: 0,987 € ($1.13)

2.2.2.Capacitor

Digi-Key Part Number: 493-15394-ND

Manufacturer Part Number: UKL1J220KPD

Cost: $0.56

2.2.3.Diode

Digi-Key Part Number: 497-7544-5-ND

Manufacturer Part Number: STPS10L60D

V_F = 600 mV

Reverse Voltage = 60V

Cost: $1.48

2.2.4.MOSFET

Digi-Key Part Number: FDS5672CT-ND

Manufacturer Part Number: FDS5672

$R_{ds(on)}$ (Drain to Source On Resistance) = 10 mOhms

Breakdown voltage = 60V

Internal diode forward voltage = 1V

Cost: $1.77

Total Cost: $4.94

2.3.Efficiency calculation

$P_{out} = I_{out} \times V_{out} = 7 \times 28 = 196$ W

2.3.1.Losses:

From MOSFET (ignore switching loss) : $P_{loss} = I_{out}^{\wedge 2} \times R_{ds(on)} \times D = 0.245$W

From diode (ignore switching loss) : $P_{loss} = V_F \times I_{out} \times (1\text{-}D) = 2.1$ W

From Inductor : $P_{loss} = I_{out}^{\wedge 2} \times R_{dc} = 2.11$ W

Efficiency = $[(P_{out}) / (P_{out} + \text{Total loss})] \times 100\% = 97.77\%$

To obtain more efficient buck converter , components need to be selected properly. For MOSFET, $R_{ds(on)}$ and gate charge must be low as possible as for fast switching.Also, diode must have low forward voltage drop.These are the key factors for efficiency.

Part 3 - Boost Converter

3.1. Design Selection

In total, Webench provided 33 designs with various ranges in efficiency, cost, bom area, inductor ripple current, crossover frequency, phase margin and bom count. In the light of these parameters the primarily chosen design merits were efficiency and inductor ripple current. As can be seen in the advanced charting in figure 9 the smallest and the most efficient design is TPS61089RNRR. Also its BOM Cos is one of the smallest amongst all the other designs. Hence those are the reasons for its selection as well as its lower inductor ripple current.

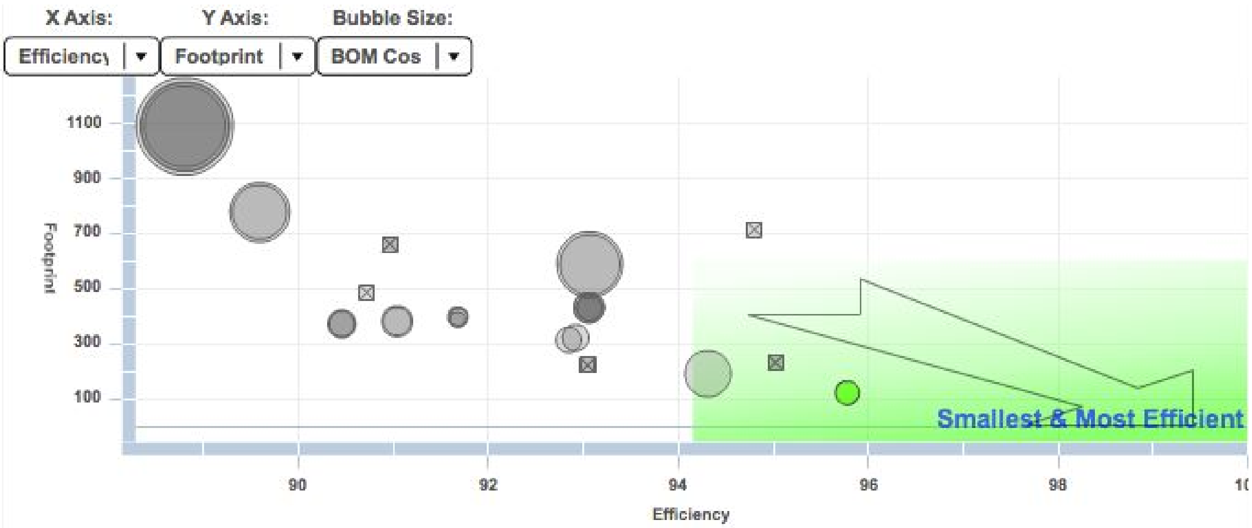

Figure 9 :Advanced charting of the available designs.

3.2.The Design

3.2.1 Circuit Schematic and Efficiency,Vout-ripple vs Output Current

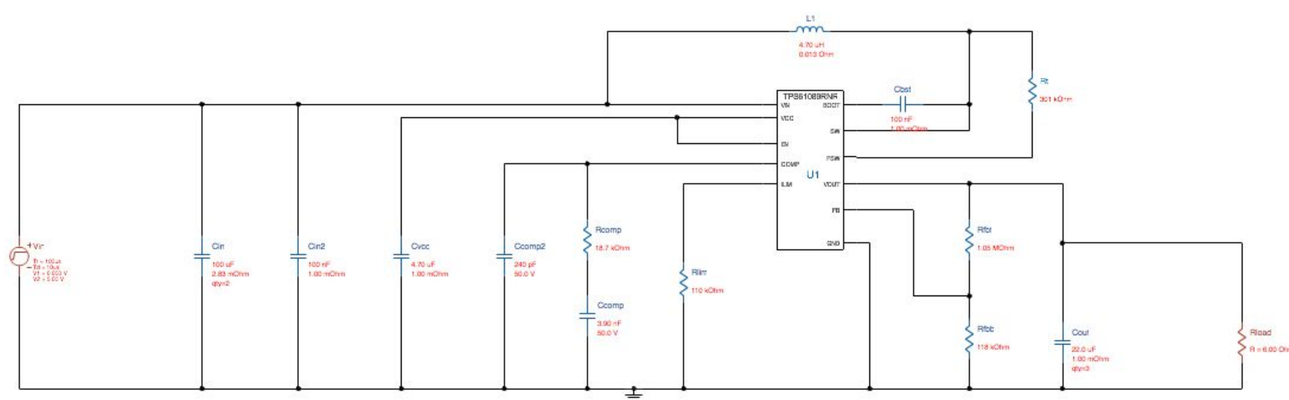

Figure 10: Schematic of TPS61089RNRR Boost converter.

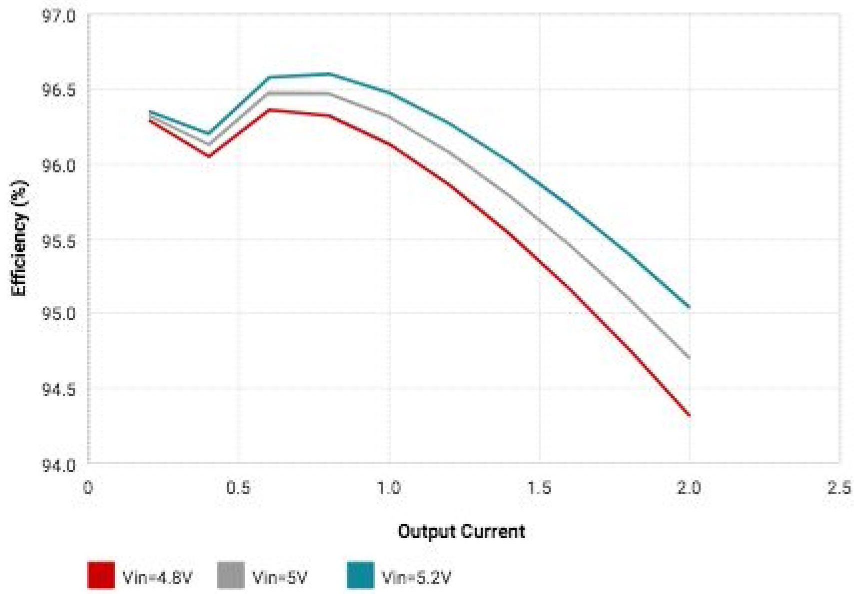

Figure 11: Graph of efficiency vs output current for minimum medium and maximum input voltage values.

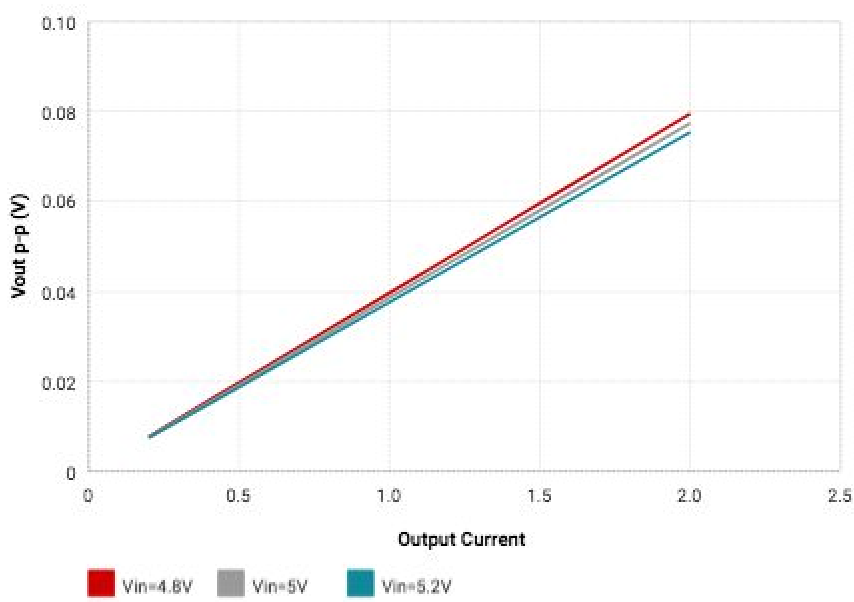

Figure 12: Graph of output peak to peak voltage vs output current for minimum medium and maximum input voltage values.

3.2.2

Inductor Current Peak to Peak Value	*1.273A*
Output Voltage Peak to Peak Value	*0.079V*
Efficiency	*94.31%*
IC Junction Temperature	*67.1degC*
Mode	*Boost CCM*
Footprint	*192mm2*
BOM Cost	*4.71$*

Table 1: Table of various design parameters

3.2.3.Graphs

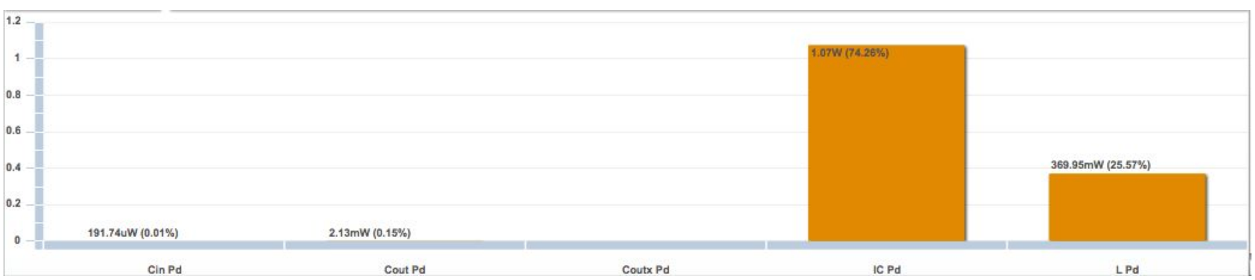

Figure 13: Power loss graph

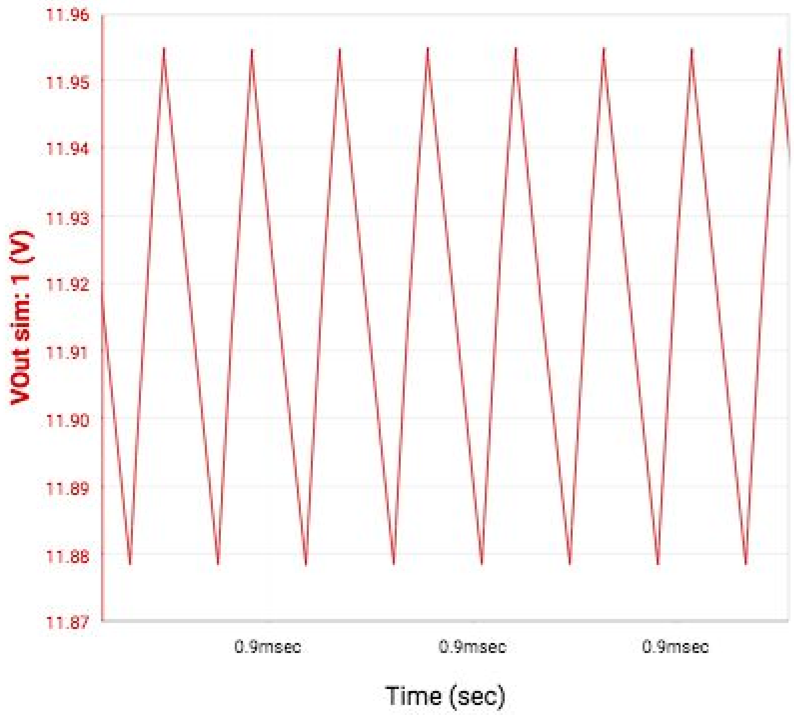

*Figure 14:Output Voltage vs Time Graph **for Steady-State***

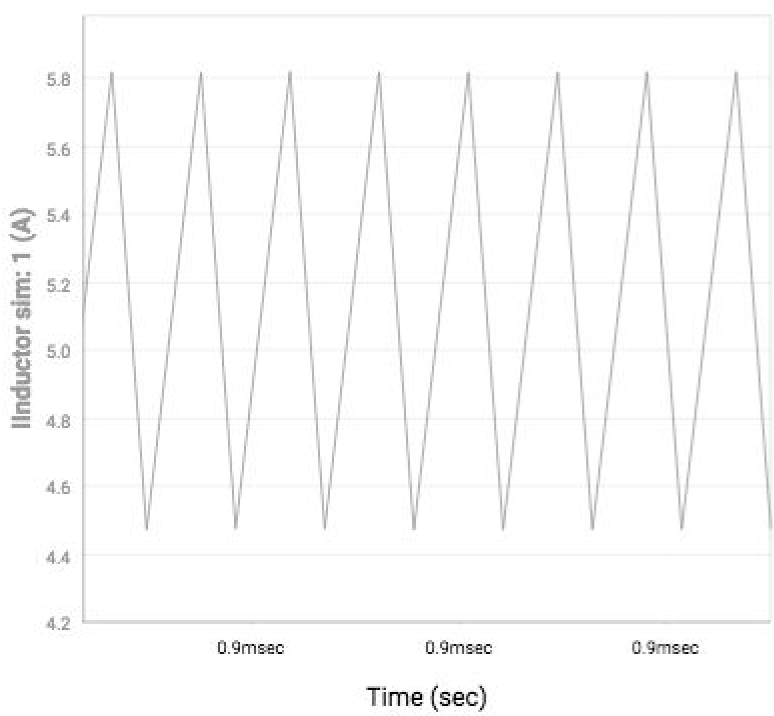

*Figure 15:Inductor Current vs Time Graph **for Steady-State***

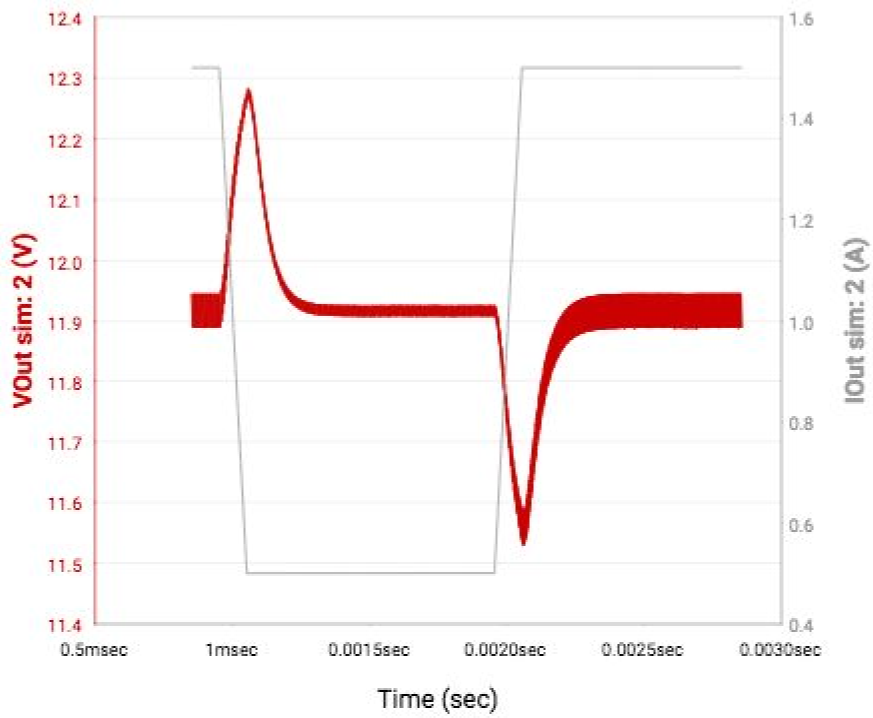

Figure 16:Output Voltage & Load Current vs Time ***for Load Transient***

In steady state the inductor current is a scaled and shifted version of the output voltage as expected. For load transient graph of V_{out} and I_{load} ripples are larger with the same frequency as I_{out} increases. As I_{out} switches from a higher value to a lower value in the load transient analysis, output voltage increases and when I_{out} reaches to the lower steady state Vout drops back to its previous state where it has the same mean value with less ripples. Therefore it can be concluded that the mean value of the output voltage does not depend on the output current in steady state.