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Date of Submission: 05.01.2019

Contents

1. Introduction

In this project using different simulation tools, we constructed different types of DC-DC converters and a motor driver with speed control from thyristor rectifier. In part 1, a PI controller is designed for speed control of an DC motor. In part 2, a buck converter is designed with the commercial circuit elements. In part 3, a boost converter is designed by using Webench. The 3-Phase values are assumed to be as Turkish grid.

This report includes the schematics of our designs and simulation results for all three parts as well as our comments, interpretations and conclusions about them.

2. Part 1 : 3-Phase Thyristor Converter

In this part of the project, we are asked to drive a DC motor by a 3-Phase thyristor controlled rectifier. We are required to design a controller which feeds the controlled rectifier with a proper angle such that the motor will have a speed which is determined by the user,i.e, to design a speed controller for the DC motor.

The firing angle will be determined by a PI controller system that takes feedback from the output speed and compare it with the desired speed value in order to feed the firing system with the corresponding angle. The simulink model of the whole system can be seen in Figure 1.

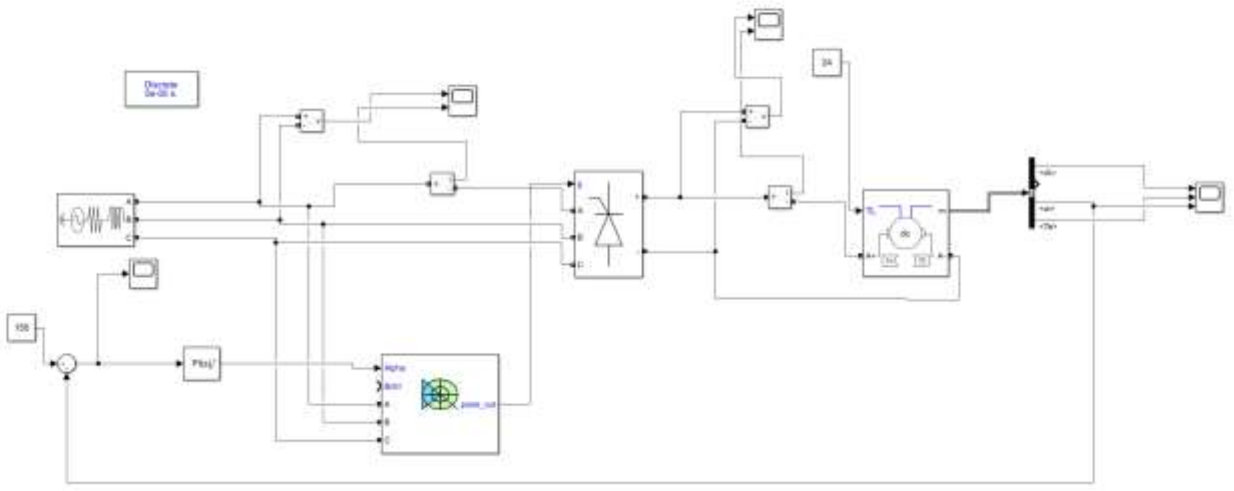

Figure 1: Simulink model of DC motor driver with speed control

As can be seen from the Figure 1, the motor driver circuit composes of a thyristor rectifier, a dc motor and a PI controller.

The controller takes the error (Difference between desired and the output speed) and produced the necessary firing angle, α. The $K$and K_I parameters of the PI controller are specified with trial and error. Various different combinations are tested and the parameters are chosen as;

$$K = -100 \text{ and } K_I = -8$$

The controller parameters can be seen in Figure 2.

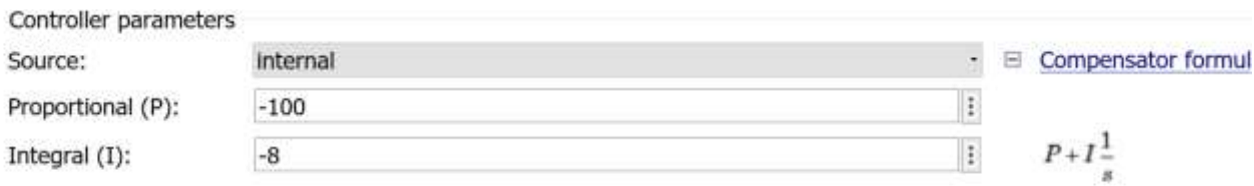

Figure 2: PI controller parameters

After choosing the parameters, we applied a driving performance test in order to test the effectiveness of our design. The results of the performance test can be seen in Figure 3.

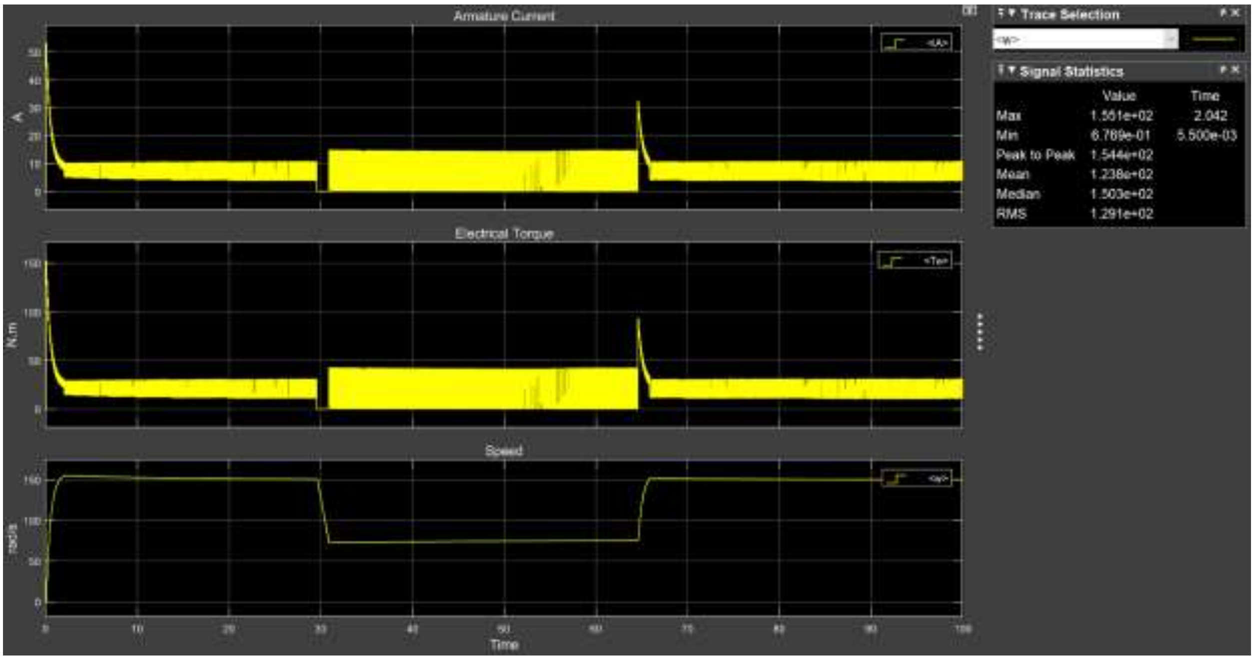

Figure 3: Driving Performance Test

Armature current, speed and torque waveform characteristics of the DC motor when the desired speed is set to 150 rad/s are can be seen below in Figure 4.

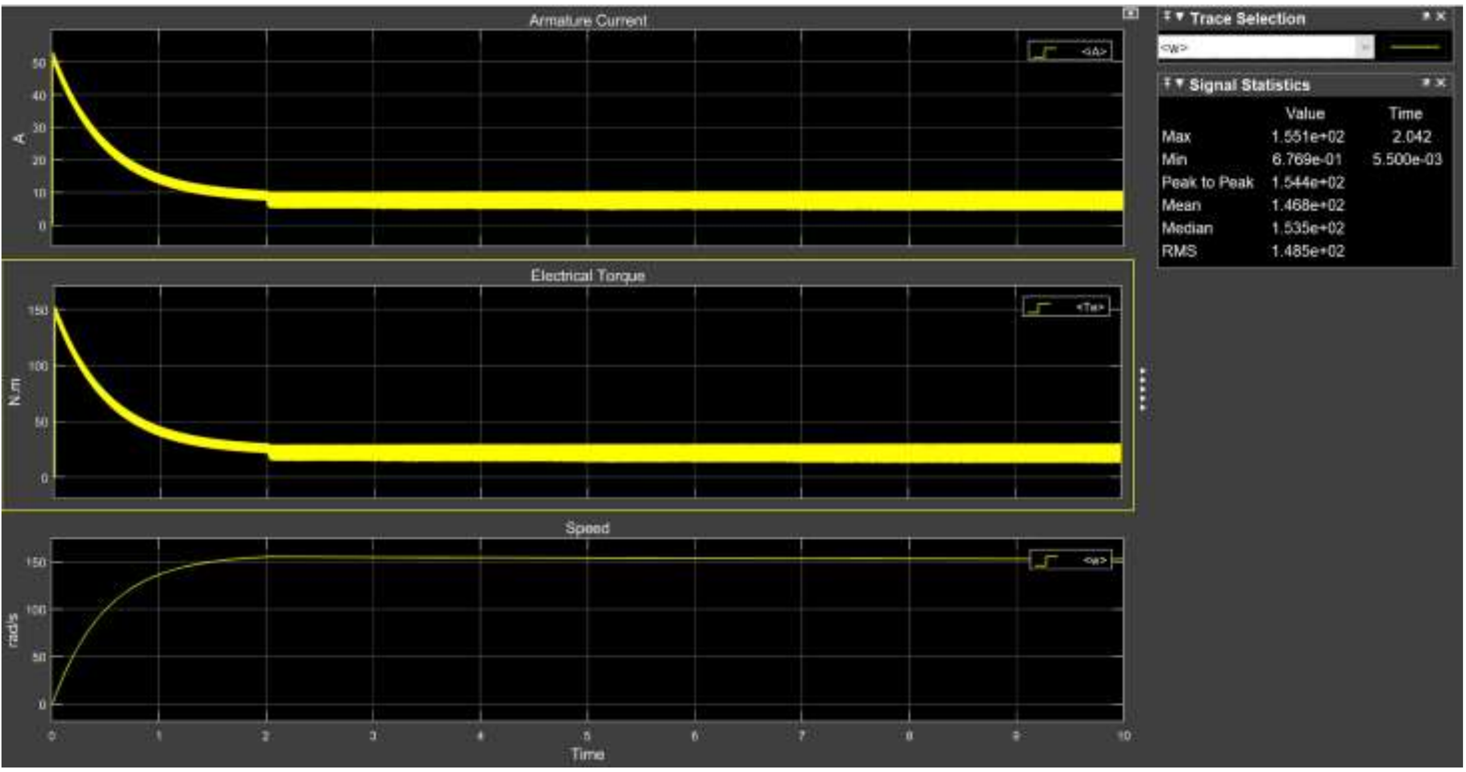

Figure 4: Armature current, speed and torque waveforms of the DC motor when the desired speed is set to 150 rad/s

We know that the electrical torque is proportional to the armature current. Hence we expect that their waveforms to resemble each other. If the torque and current lines in figure 4 are examined, it can be seen that indeed, this is the case. They look exactly the same, except that there is a proportionality constant between them.

One can also see that speed is inversely proportional with the torque and the armature current. Hence, in order to speed up the motor, the armature current should be decreased and vice versa.

From the Figure 3 and Figure 4, we can see that torque and armature current make a maximum when motor is started from the zero speed. This is also the case for when we try to increase speed from 75 rad/s to 150 rad/s. This is because when the speed is low, induced armature voltage is low and this make armature current very high.

3. Part 2 : Buck Converter

In this part, we are asked to design a buck converter with a power mosfet which will convert 56 Volts to 28 Volts when the load is 4Ω. The circuit schematic of our buck converter design can be seen below in Figure 5.

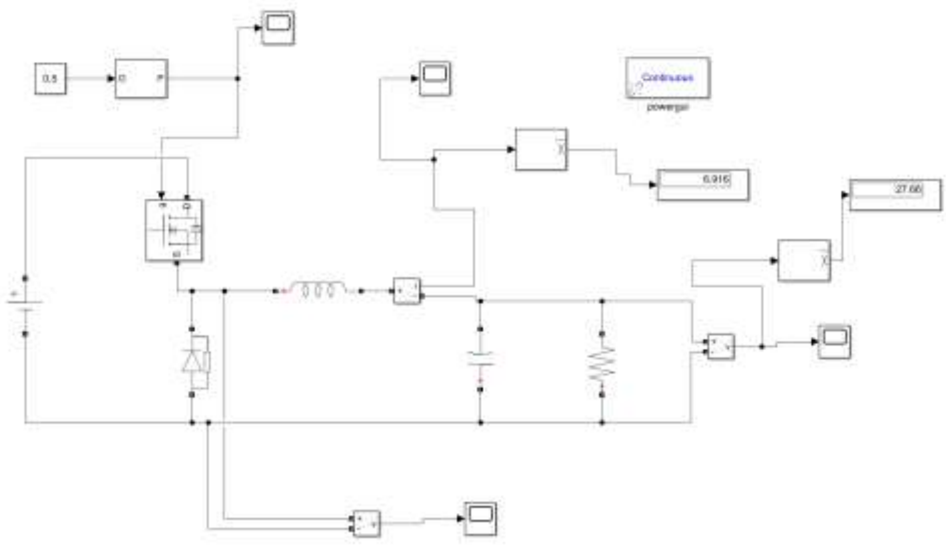

Figure 5: Buck Converter design

We obtained an output voltage of 27.66 V which is very close to 28. The output voltage and inductor current waveforms can be seen in Figure 6 and Figure 7.

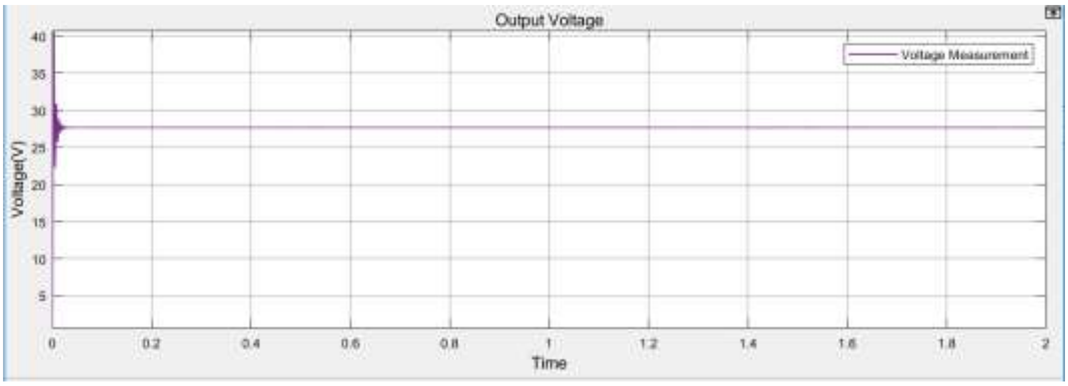

Figure 6: Output Voltage of the Buck converter

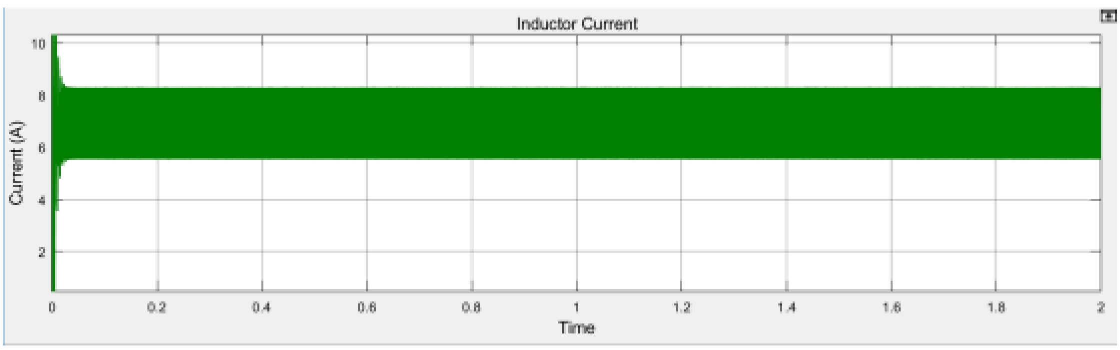

Figure 7: Inductor Current of the Buck converter

Output voltage ripple can be calculated theoretically by the following formula;

$$\Delta V_o = \frac{V_o \times (1-D)}{f_s^2 \times 8 \times L \times C} \qquad (1)$$

Where D is the duty cycle, f_s is the operating frequency and V_o is the output voltage. We operate at 5 kHz with a duty cycle of 0.5 and the inductance and capacitance values we have have chosen are 1 mH and 680 µF respectively.

When the values are put into the equation,

$$\Delta V_o = \frac{27.66 \times (1-0.5)}{25 \times 10^6 \times 8 \times 10^{-3} \times 680 \times 10^{-6}}$$

$$\Delta V_o \simeq 0.1017 \text{ V}$$

The ripples of the output voltage waveform can be seen below in Figure 8.

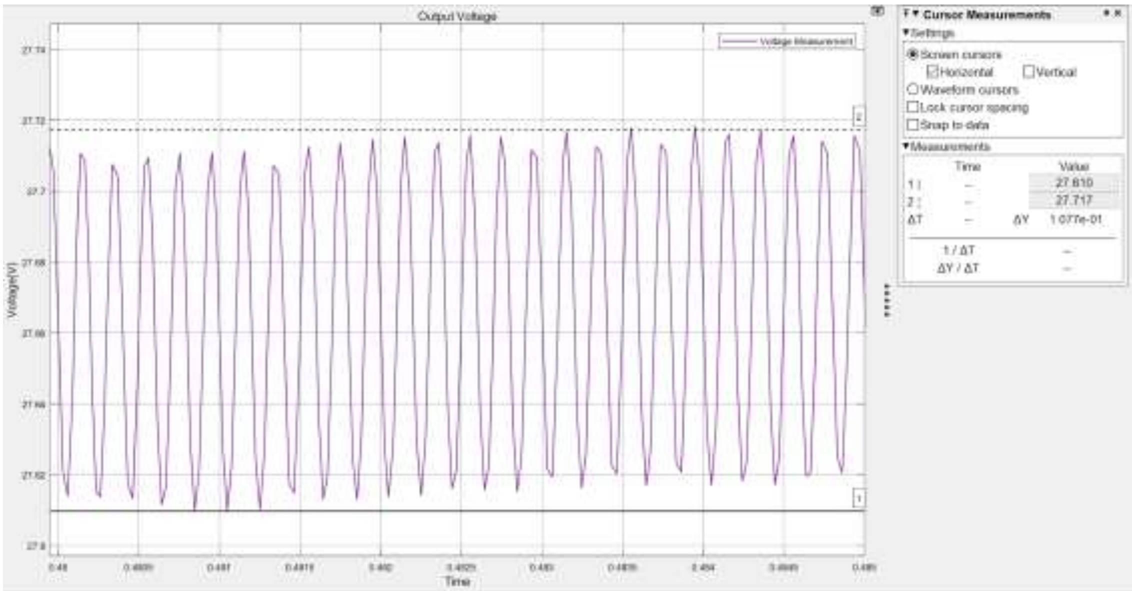

Figure 8 : Output Voltage Ripple

As one can see from Figure 6, output voltage ripple is 0.1077 V which is approximately same with the value calculated theoretically.

Inductor current ripple can also be calculated by the formula below;

$$\Delta I_L = \frac{V_O \times (1-D)}{L \times f_s} \qquad (2)$$

Using the formula, ripple in the inductor current is calculated as,

$$\Delta I_L = \frac{27.66 \times (1-0.5)}{10^{-3} \quad \times 5 \times 10^3}$$

$$\Delta I_L = 2.766 \text{ A}$$

The inductor current ripples can be seen in Figure 9.

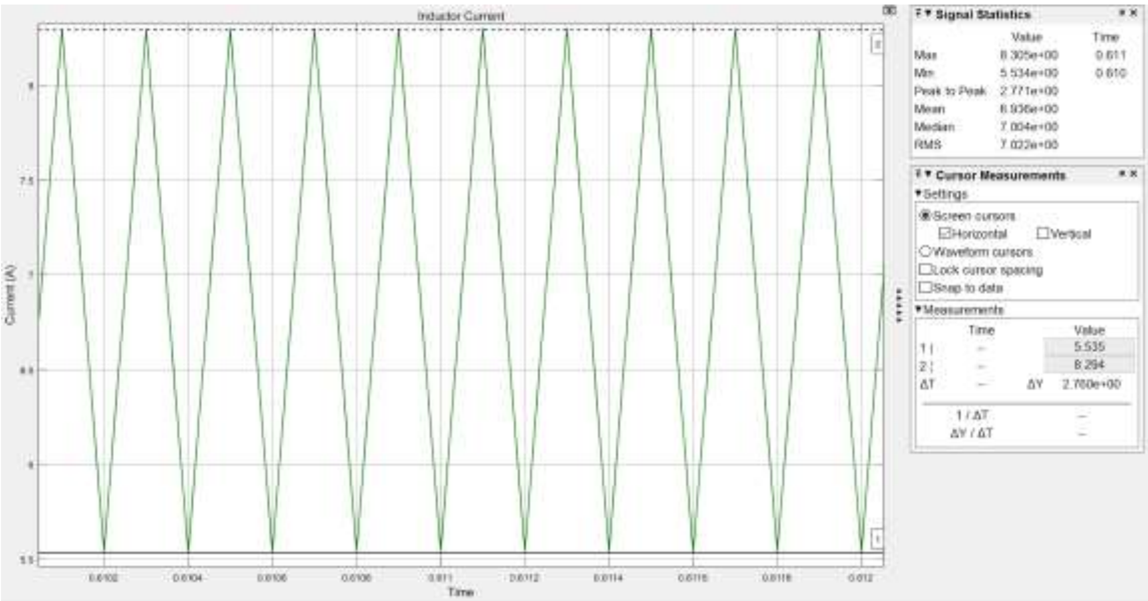

Figure 9: Inductor current ripples

As one can see from Figure 9, inductor current ripples are 2.760 A in the simulink simulations. We can conclude that simulation results are almost the same with the theoretically calculated ones.

Chosen Components

Inductor

An inductor with an inductance value of 1 mH is chosen.

The commercial product that we have chosen can be found at the following link.

https://www.mouser.com.tr/ProductDetail/Wurth-Electronics/744824101?qs=sGAEpiMZZMv126LJFLh8yyIZIOICTdvmFFbNAomols8=

Product Code: 744824101

Cost : 4.80 €

Manufacturer : Wurth Electronics

Inductance : 1mH

Rated current : 10A

Rated voltage : 250 V

Capacitor

A capacitor with an capacitance value of 680 µF is chosen.

The commercial product that we have chosen can be found at the following link.

https://www.mouser.com.tr/ProductDetail/Panasonic/EEU-FS1K681?qs=sGAEpiMZZMsh%252b1woXyUXj3Q6FWM8D%252bEZ7tEUZEF2iGo%3d

Product Code: EEU-FS1K681

Cost : 1.60 €

Manufacturer : Panasonic

Inductance : 680 µF

Voltage Rating DC : 80 V

Ripple Current : 2500 mA

Power Mosfet

The commercial product that we have chosen can be found at the following link.

https://www.mouser.com.tr/ProductDetail/Toshiba/TPH6400ENHL1Q?qs=%2fha2pyFadujw3EJGnGH7Xq6uLf8lhobuacLcz0bgNX7H9Z0c5%2fn%2faA%3d%3d

Product Code: TPH6400ENH,L1Q

Cost : 1.38 €

Manufacturer : Toshiba

Inductance : 680 µF

Voltage Rating DC : 80 V

Ripple Current : 2500 mA

Transistor Polarity : N-Channel

Vds- Drain Source Breakdown Voltage : 200 V

Id - Continuous Drain Current : 13 A

Rds On -Drain Source Resistance : 54 mOhms

Diode

The commercial product that we have chosen can be found at the following link.

https://www.mouser.com.tr/ProductDetail/ON-Semiconductor/MBRF10H150CTG?qs=sGAEpiMZZMtoHjESLttvkpHLBuj34cQgzmwc7Ko2Dqc%3d

Product Code: MBRF10H150CTG

Cost : 0.75 €

Manufacturer : ON Semiconductor

Peak Reverse Voltage : 100V

Forward Current : 10 A

Forward Voltage : 0.85 V

Reverse Current : 45µA

Overall Cost

The overall cost computation can be seen in the table below.

Component	**Cost**
Inductor	4.80 €
Capacitor	1.60 €
Power Mosfet	1.38 €
Diode	0.75 €
Total	**8.53 €**

Table 1: Cost Analysis

Overall Efficiency

There is an average current of 6.917 A flows from the load, leading a power dissipation of ;

$$6.917 \times 27.67 = 191\ W$$

The leakage current of the capacitor is found as 0.01 µA from its datasheet. Hence the power dissipated on the capacitor becomes;

$$0.01 \times 10^{-6} \times 27.67 = 27.67 \times 10^{-8} W$$

The DC resistance of the inductor is found as 14 mΩ. So, the power dissipated on the inductor becomes;

$$14 \times 10^{-3} \times 6.916 = 0.096824\ W$$

The power dissipation on mosfet is calculated from its $V_{DS} - I_D$characteristics which can be seen in Figure 10 taken from its datasheet. Drain current of the Mosfet is around 8.35 A in the simulink simulations.

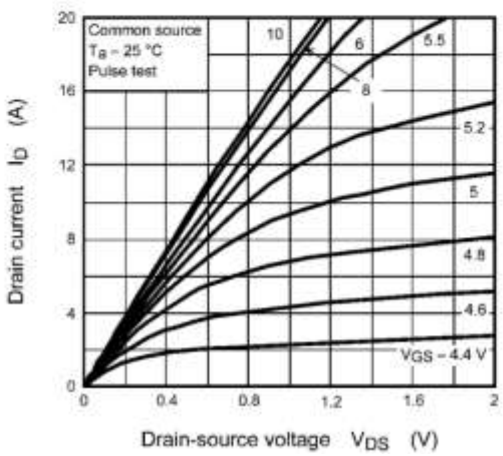

Figure 10: V_DS-I_Dcharacteristics [1]

As can be seen from Figure 10, when we look at the V_{DS} corresponding to the 8.35 A, we can say that it is around 0.9 V (V_{GS} is taken as 5 V).

Hence the power dissipation on the mosfet becomes;

$$0.9 \times 8.35 \times 0.5 = 3.7575$$

The power dissipated on the diode is found by looking at the average power dissipation graph that can be seen in Figure 11 from its datasheet.

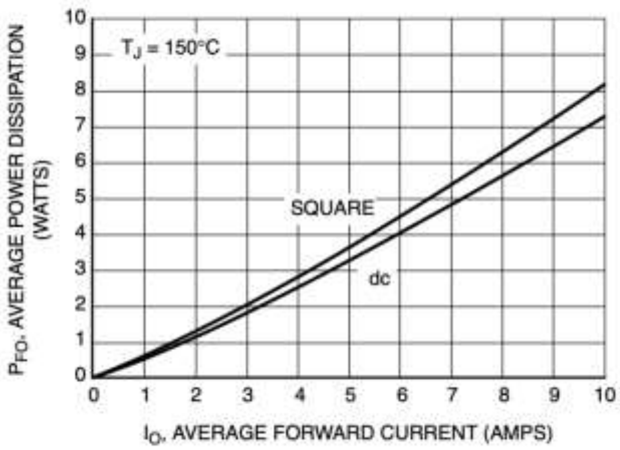

Figure 11: Average power dissipation curve of the chosen diode[2]

As one can see from Figure 11, when the current is 8.35 A, the power dissipation is around 6 W. Since we have 50% duty cycle, 3 W is dissipated on the diode.

Total efficiency calculation :

$$n = \frac{191}{191 + 3 + 3.7575 + 0.096824 + 27.67 \times 10^{-8}} \times 100$$

$$n = 96.53\%$$

The diode and the mosfet are the most effective elements on the overall efficiency. Capacitor is the least effective components since we have chosen one with a very small leakage current.

4. Part 3 :Boost Converter

4.1)

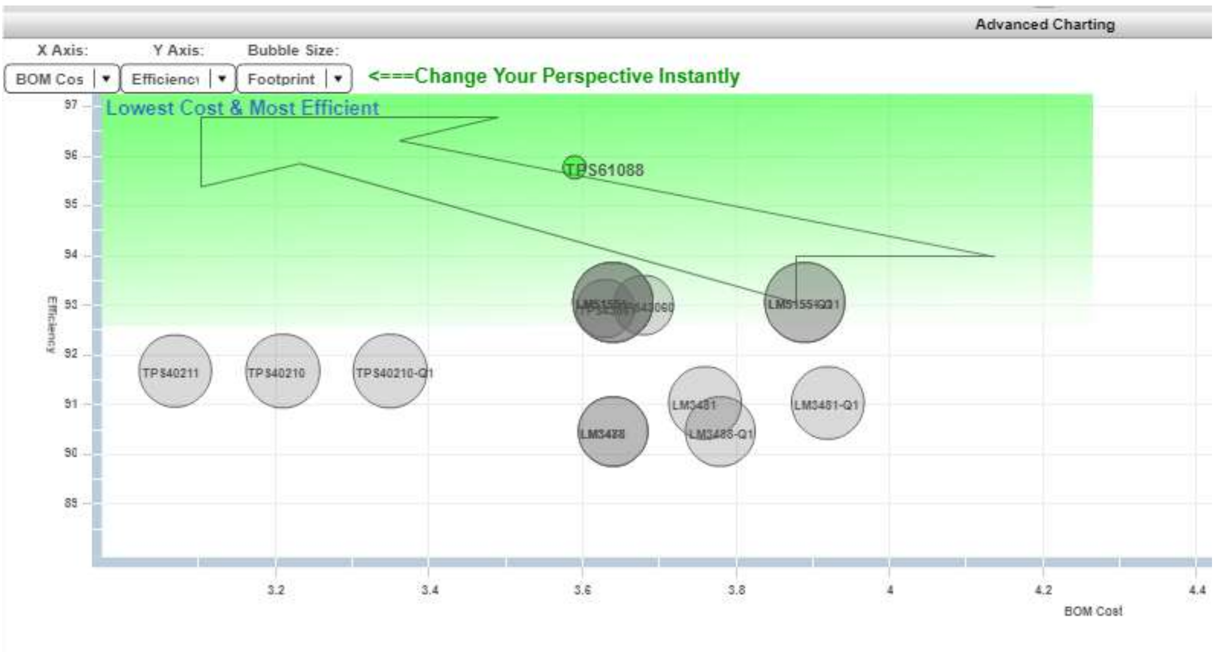

Figure 12: Advanced Charting for Boost Converter Components

There are so many factors to select electronic components in order to construct your electronic devices. The three most important factors among them: Cost, Efficiency, and Footprint. Cost is important because we want to reduce the cost of the product to increase the revenue of the company. Also, efficiency is important because we want the product to work with high performance for more efficient working performance. In addition, the smaller the area of the product, the more aesthetic in the product design, the ease of transport and other electric components provide space.

We can easily observe the impact of these three factors on Figure 12 Advance Charting. Y represents axis efficiency, X represents the axis cost and Bubble Size represents the footprint. In evaluating these three factors while making our selection, we found the TPS61088 component to be the most optimum. Because the number of products that we will produce will be low, it will tolerate itself as a price. In addition, with reduced efficiency of component could deform over time and cause more serious cost losses. Also the heat energy released by the decrease of efficiency will increase and because of this reason, it also reduces the sustainability of the device. Therefore, efficiency is the most important factor for us. In addition, the TPS61088 component has a very small footprint, which further increases the accuracy of our selection.

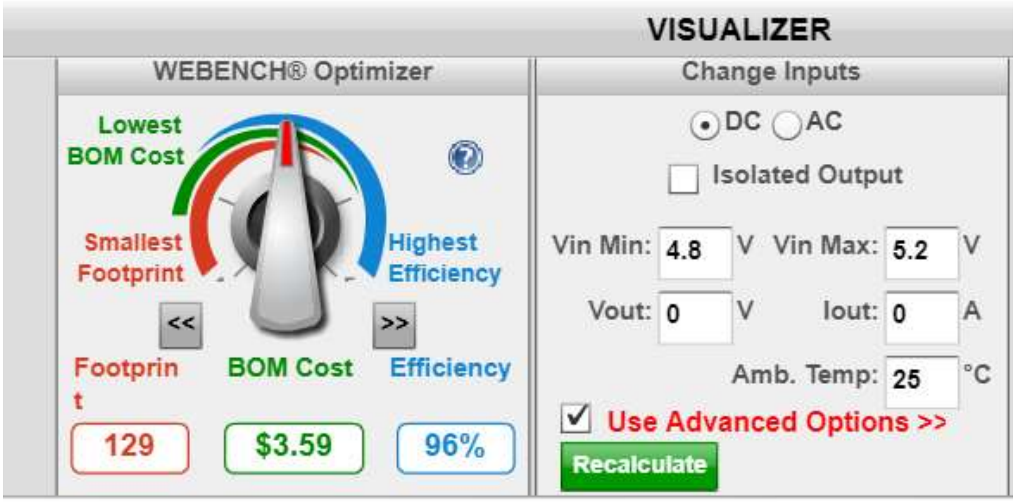

Figure 13: Webench Optimizer Tool

4.2)

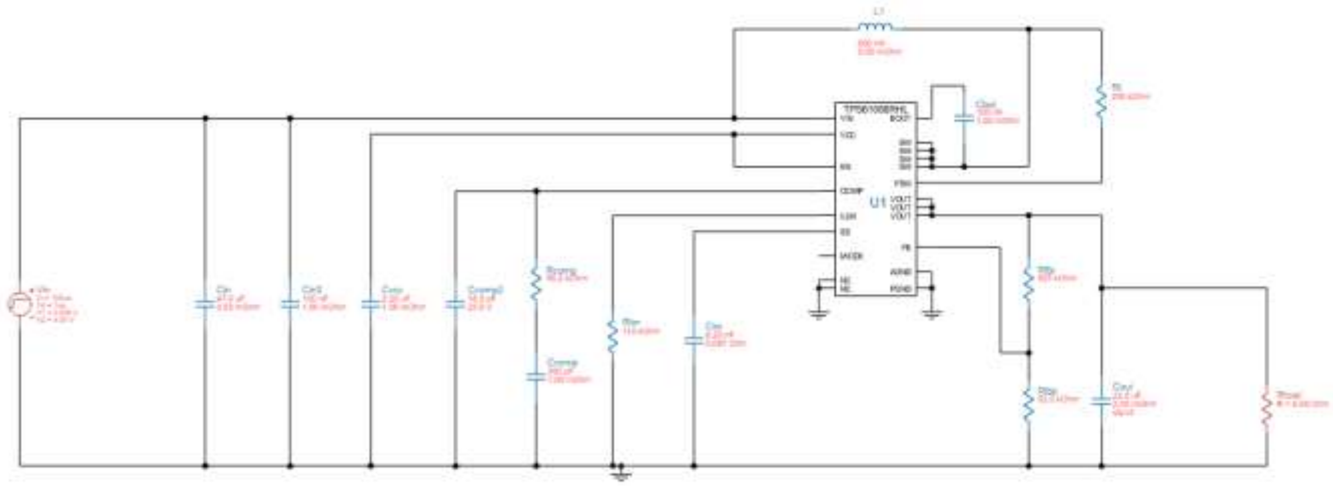

Figure 14: Schematic TPS61088 (Boost Converter)

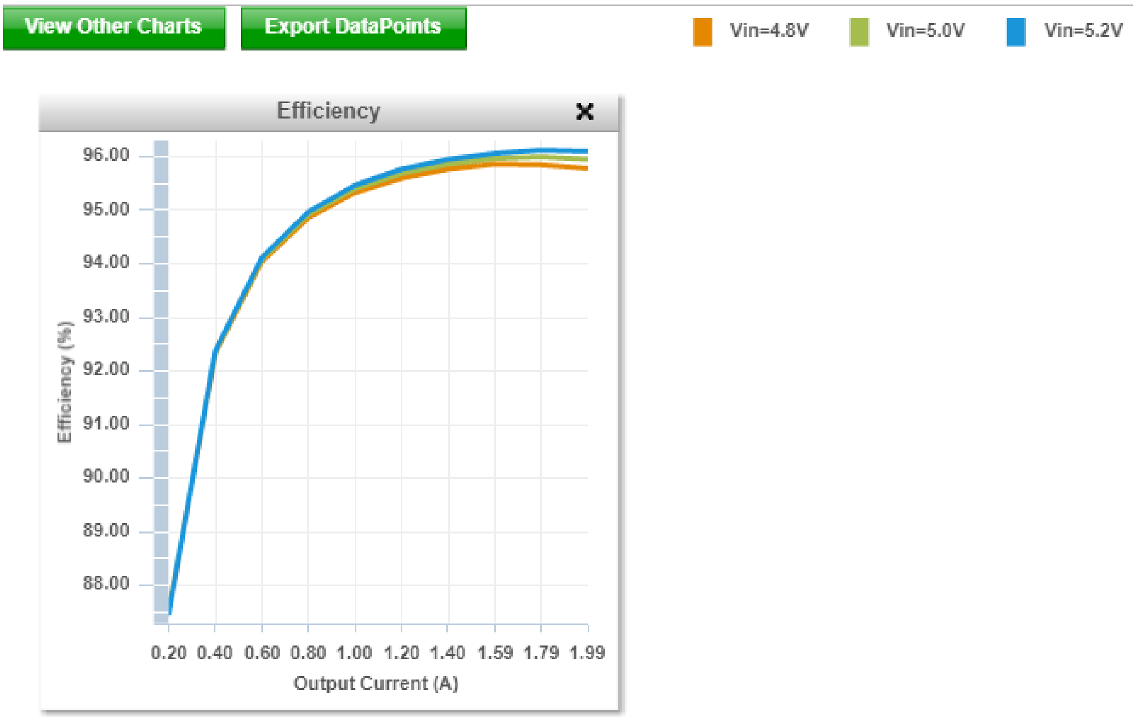

Figure 15: Efficiency Vs Output Current Graph

Power is increasing in proportion to the square of the current. We expect Power loss to increase correctly with the square of the current. However, the power loss ratio of compenents with respect to load power is decreasing gradually. This is due to some factors that do not depend on the increase of the current. For example , voltage drop on diode isnt observed considerable change on diode related to increasing of current at operation mode.Then, while Load power increases on related to increasing current, most of the losses are increasing with a slower rate. Therefore, efficiency increases.

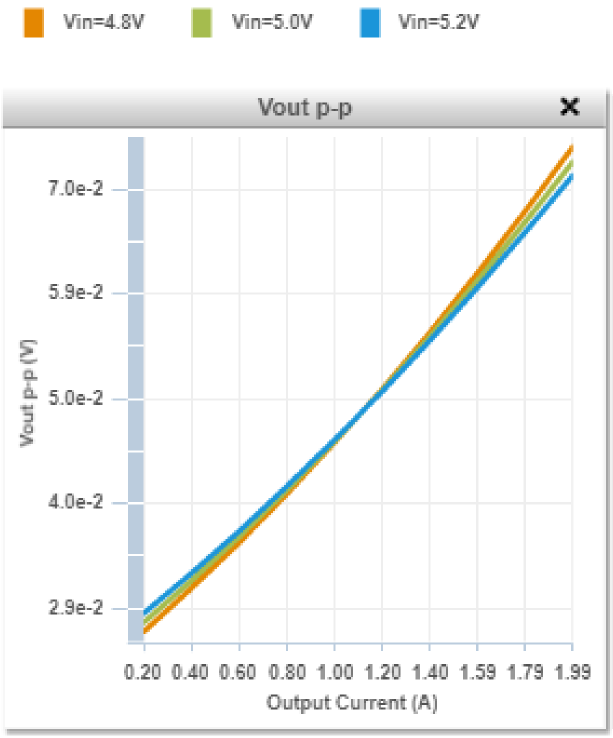

Figure 16: Output Voltage Ripple vs Output Current Graph

Principle of boost converter working systems similar like Ramp Pump systems. At boost converter when diode is open, the load is charging by source . Also when diode is closed , the load is fed from capacitor. Therefore more output current flows, the more capacitor supplies current to the load. As capacitor discharges more with increasing load current, more output voltage is observed on capacitor voltage(ripple voltage.)

Op-Vals Section

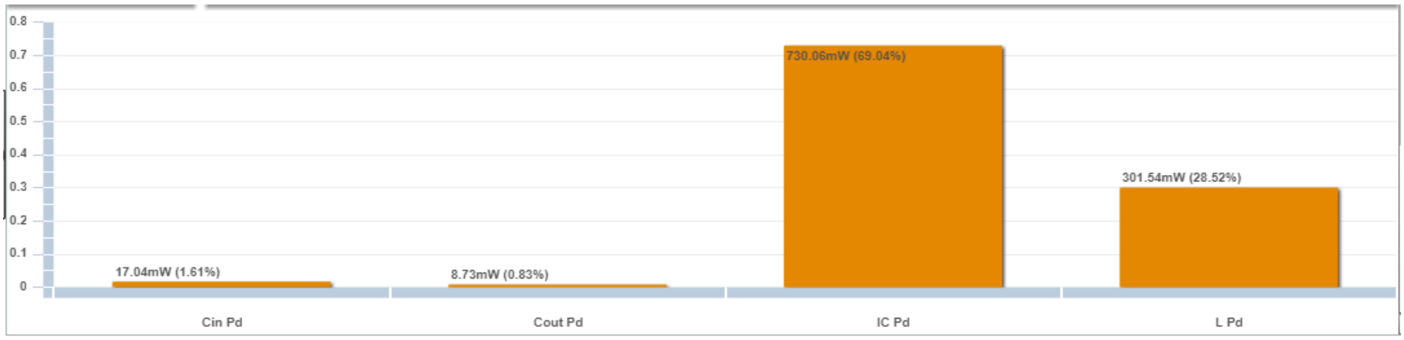

Figure 17: Power loss graph of components

Inductor Current Peak to Peak Value	8.204A
Output Voltage Peak to Peak Value	0.074V
Efficiency	95.78 %
IC Junction Temperature	53.3 degC
Mode	Boost CCM
Footprint	123mm^2
BOM Cost	3.53$

Table 2: Properties of TPS61088 (Boost Converter)

4.3)

Steady state operation

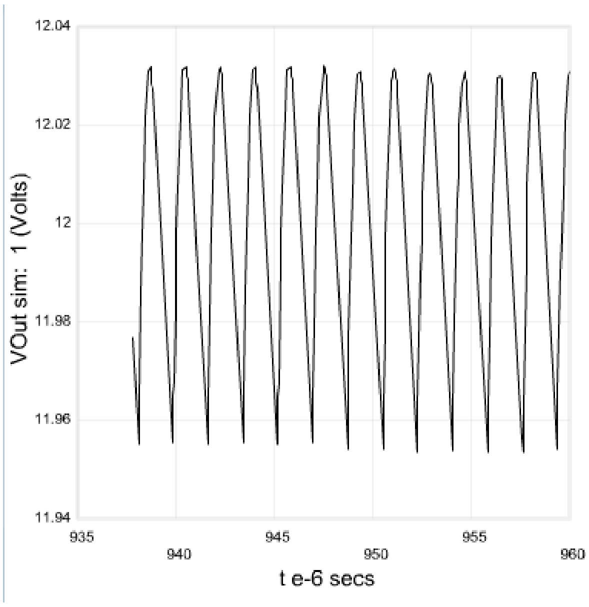

Figure 18: Vout vs time graph at steady state

Based on our expectations, we obtained approximately 12 volts on the output voltage graph. Because of the high efficiency of the selected device, our ripple value is also very low. The Ripple value is approximately 0.1 Volts and these results are the desired value.Also, the time that switch is opened, the capacitor is fed from source current , then voltage increases. On the other hand, the time that switch is closed, the capacitor feeds the load ,then voltage ecreases. Because of this mechanism, we observed this voltage ripple in this figure.

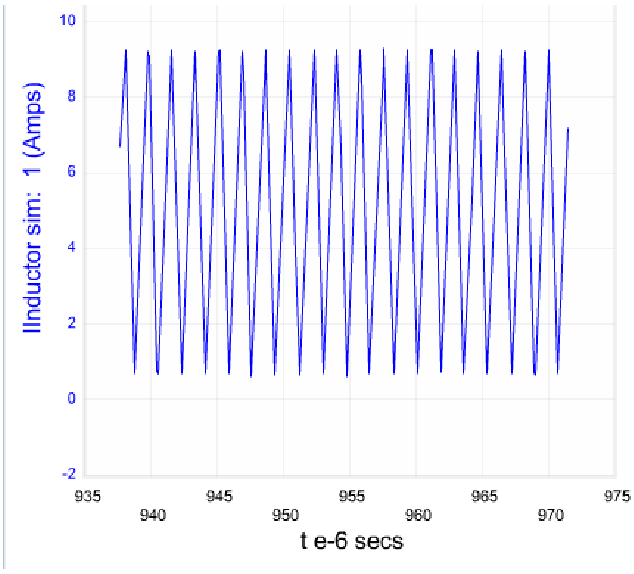

Figure 19: inductor Current vs Time Graph for Steady-State

As ssen figure , the time that switch is opened, the inductor is fed from the voltage(Vout - Vin) which is negative value, then current decreasses. On the other hand, the time that switch is closed, the inductor is fed the source Voltage (Vin) ,then current increases.

Load Transient

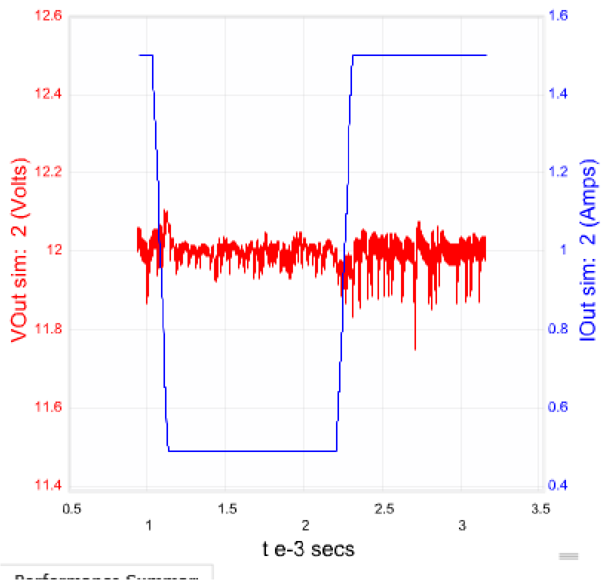

Figure 20 : Output Voltage & Load Current vs Time for Load Transient

5. Conclusion

In this report we presented the results of Software Project 3, alongside with the simulation results for our designs in every separate part of the project.

In part 1, we constructed a thyristor full bridge rectifier driving a DC motor and then designed a PI controller to control its speed. We determined the controller parameters are test our design with a performance test. We observed the torque and armature current characteristics when speed is goes from a low value to high and vice versa.

In part 2, we designed and constructed a buck converter in Simulink. We chosen the circuit elements from the commercially avaliable components and see that how sometimes it can be difficult to find the component exactly with the desired characteristics. Moreover, while doing the design we observed how the duty cycle is effective on the output voltage and how operating frequency can reduce both inductor current and output voltage ripple. We also saw that the capacitor is only affects the output voltage ripple while it has no effect on the inductor current.

In part 3, The observed which factors we have to consider to select boost converter components such as cost , efficieny and footprint. Then we simulated our selection, then oberver whether it is available performance.Moreover, all these process we designed with Webench of Texas Instrument, then we learn how to use it for comparing performance of components, analyysing and simulating of these components., experience on Webench of Texas Instrument, which is very useful and practical for choosing proper elements for desired converter and simulating and analysing it.

6. References

[1] TPH6400ENH. (n.d.). Retrieved from http://toshiba.semicon-storage.com/ap-en/product/mosfet/detail.TPH6400ENH.html

[2] MBRF10H150CTG. (n.d.). Retrieved from https://www.onsemi.com/pub/Collateral/MBRF10H150CT-D.PDF