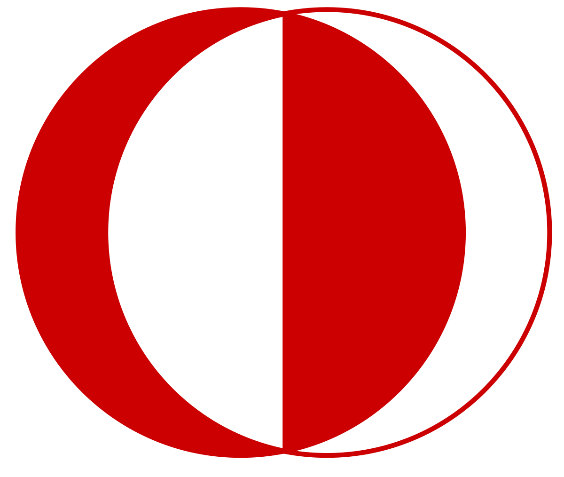
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**MIDDLE EAST TECHNICAL UNIVERSITY**

**DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING**

**E463 – PROJECT #3**

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**05.01.2019**

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# INTRODUCTION

# QUESTIONS

## QUESTION 1: 3-Phase Thyristor Converter

In this question our goal is to design a proportional-integral (PI) controller that makes the motor speed to follow the reference input speed change by changing the firing angle of a 3-phase thyristor converter. PI controller is used to reduce, or ideally eliminate, the steady-state error between the measured motor speed and reference speed. In Figure Q1.1, the feedback control system is shown.

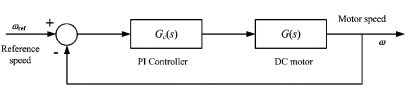


Figure Q1.1: Closed loop feedback control system of DC motor

Transfer function of the PI controller is given by (1). To design a proper controller, the dynamics of the DC motor should be described by a transfer function as well. However, with the help of tuning application methods of Simulink that will not be necessary.

Feedback control system schematics can be seen in Figure Q1.2, plant to be controlled is labeled as DC Motor. Inside the plant can be seen in Figure Q1.3. Upper and lower limits for PI output are included as 90 and 0 to obtain positive voltage mean at the armature terminals.

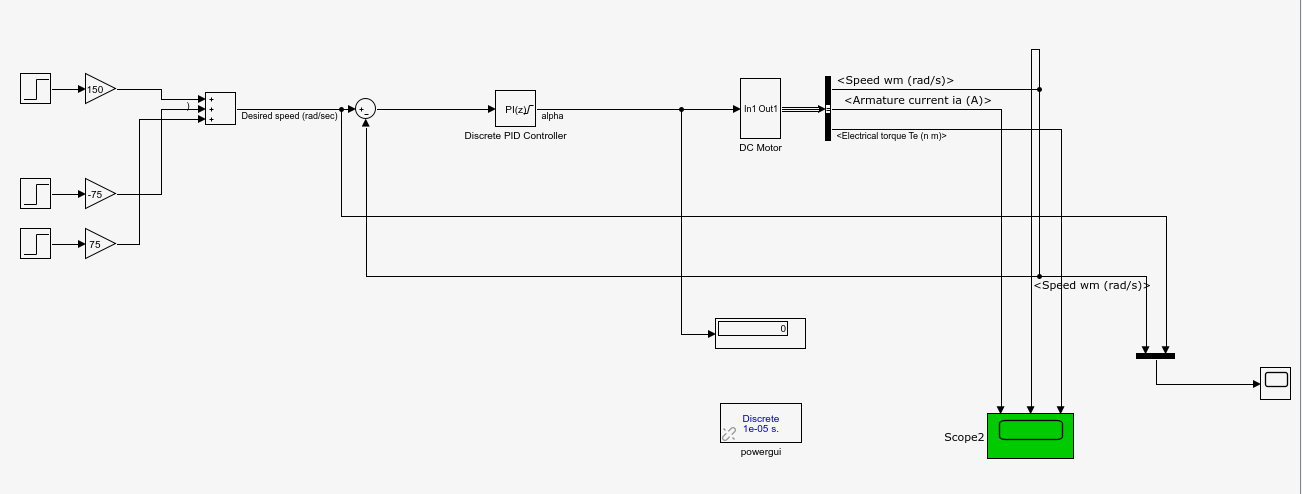


Figure Q1.2: Feedback control system

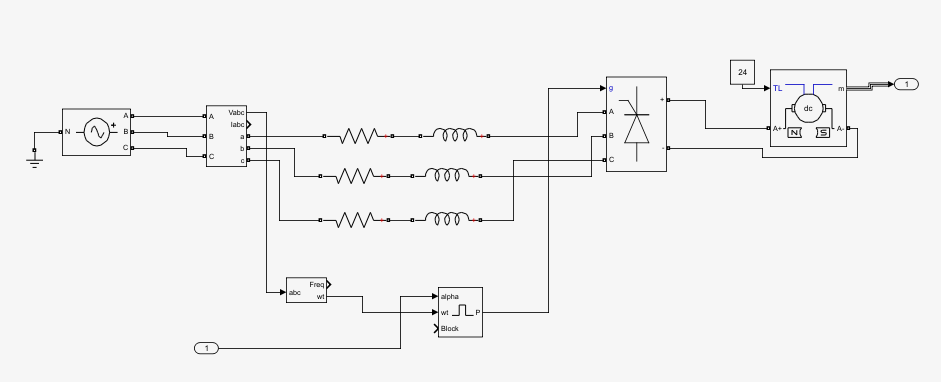


Figure Q1.3: Inside the plant

To model the controller at first, we tried to use Transfer Function Based (PID Tuning) tuning method, which linearizes the plant, calculates PID gains, and opens GUI to adjust respond time however, we could not fix ‘’initial stabilizing controller” error that we received. Therefore; we used Frequency Response Based Tuning Method and found Kp and KI as -2.0474 and -3.7927, respectively. Note that transfer function of the controller is a little different than (1), since it is a discrete time PID controller block. Motor speed and reference speed comparison can be seen in Figure Q1.4, and armature current, speed and torque waveforms can be seen in Figure Q1.5.

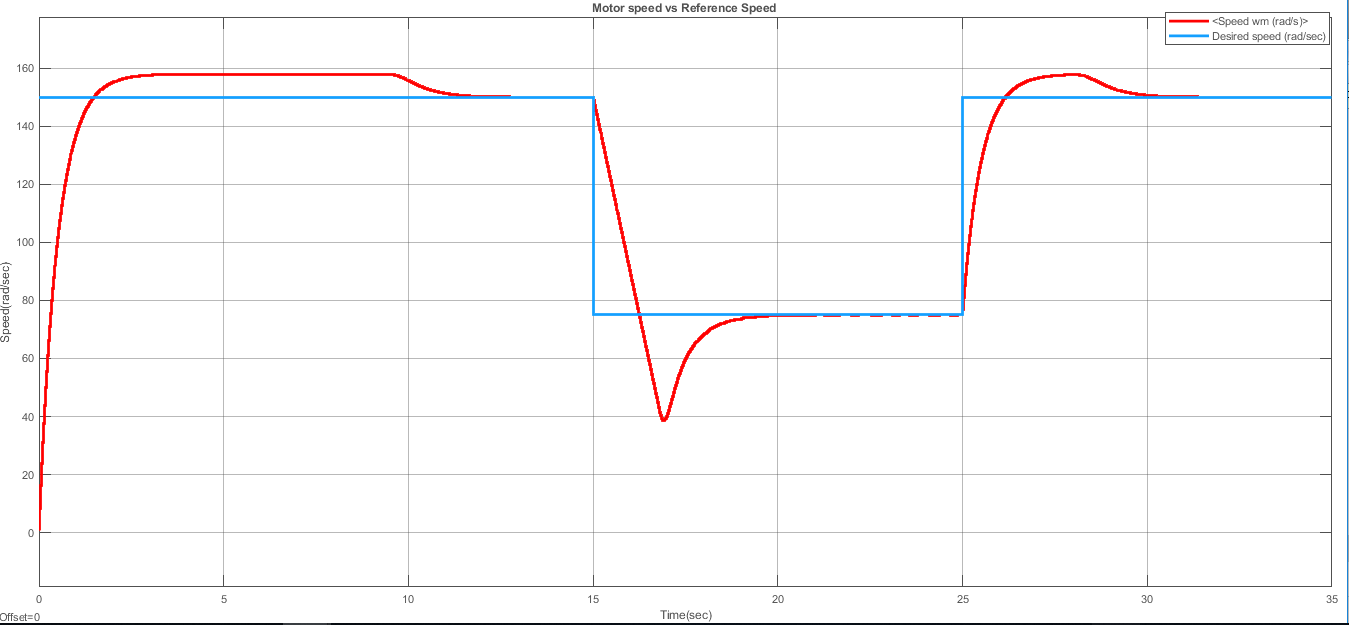


Figure Q1.4: Reference and motor speed comparison

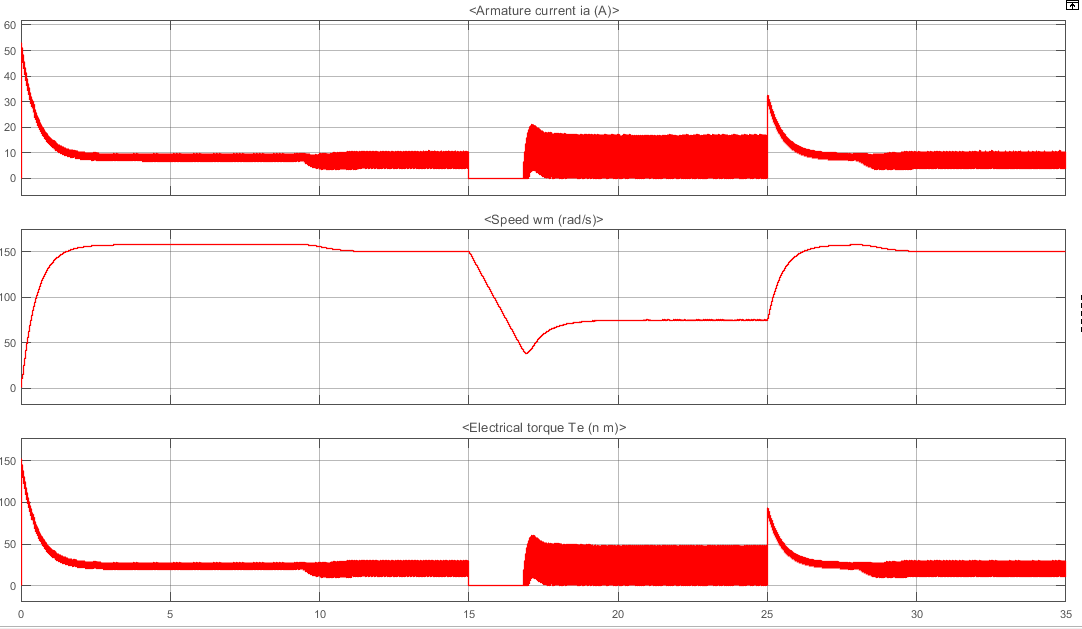


Figure Q1.5: Armature current, speed and torque waveforms

From Figure Q1.4-5 we can see that motor speed reaches zero steady state error eventually due to the integrator in the PI controller. We used various Kp and KI values but the characteristics of these waveform did not change much. However, after only using P controller and PI controller we have figured out that with P controller we cannot reach zero steady state error and with PI controller any amount of KI guarantees overshoot. Also, from Figure Q1.5 we can see that torque waveform persuades armature current waveform oscillations as it was observed in Project 2 as well.

In Figure Q1.4 we can see that motor takes some time to decrease its speed to 150 rad/sec from 157 rad/sec when we first start the motor. Changing Kp and KI values did not help this problem. However, using a different driving technique by gradually increasing the reference speed from zero to 150 rad/sec decreases the starting time from 12 seconds to 8 seconds as it can be seen from Figure Q1.6. Armature current, speed and torque waveforms again repeated for this driving technique in Figure Q1.7.

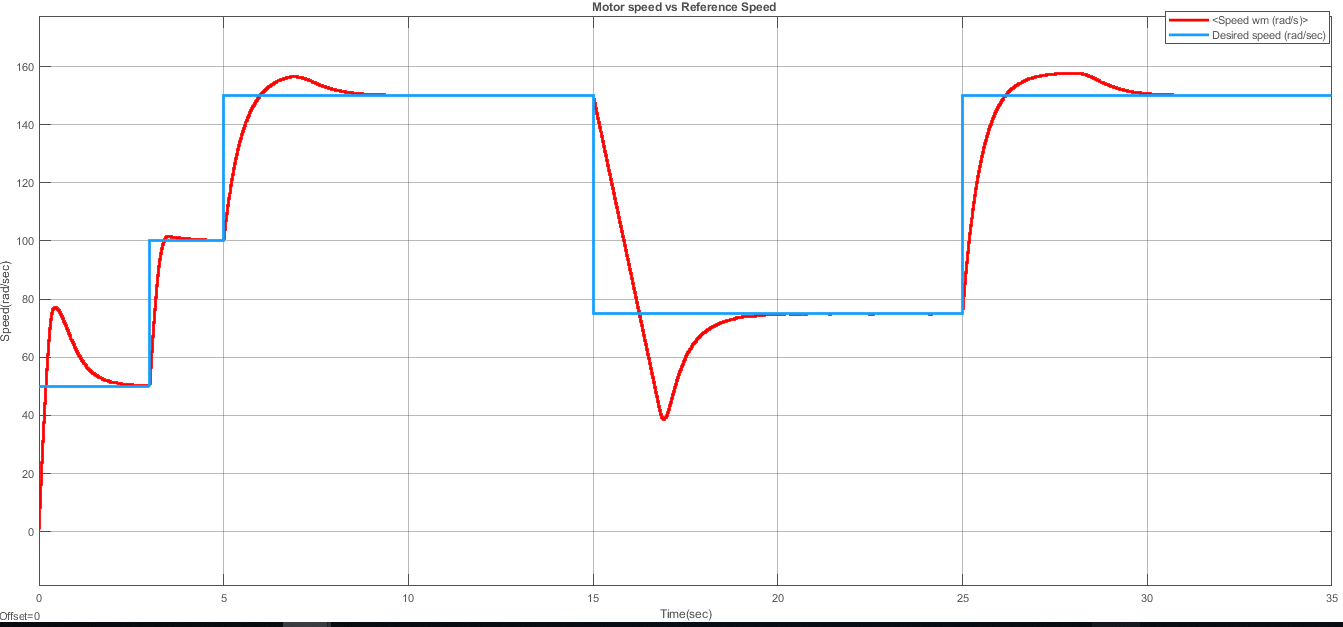


Figure Q1.6: Reference and motor speed comparison

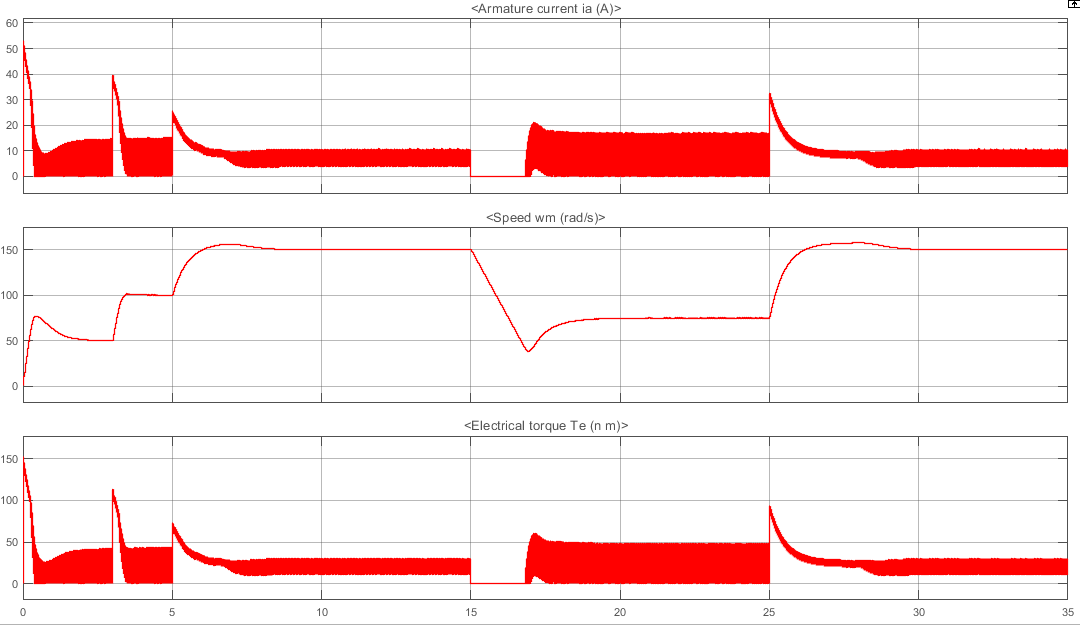


Figure Q1.7: Armature current, speed and torque waveforms

## QUESTION 2: Buck Converter

In this part of the project we are asked to design a buck converter. To achieve successful operation we need determine values of switching frequency and commercially available circuit elements. Let’s begin with using;

Vin x D = Vout , Since we know input and output voltages. Duty ratio is found 0.5. For D=0.5 we know that;

Iout / ILB, max > 1 so that we can avoid being at discontinuous conduction mode. Since

ILB, max = Ts x Vin / 8 x L putting know values into this equation we found;

L / Ts > 1 or L x fs > 1

After finding this final relationship we can determine switching frequency and inductance value. In order not to select too big inductor we select fs=20 kHz. Selected inductor and its parameters listed in Table 2.1.

Table 2.1: Selected inductor and its parameters

|  |  |
| --- | --- |
| Product code | IHB5EB331K |
| Datasheet | <http://www.vishay.com/docs/34015/ihb.pdf> |
| Inductance | 330 µH |
| Current Rating | 7.3 A |
| DCR | 49 mOhm (max) |
| Price | $16.99625 |

Note that altough we can select an inductor with smaller inductance value we select an inductor with highest possible inductance value that meets our criteria. Reasons is with higher inductances we can get lower ΔiL  so that we can have lower output voltage ripple.

ΔVout / Vout =π2 x (1-D) x (fc / fs) / 2

Considering voltage ripple and corner frequency should be much smaller than switching frequency a capacitor is selected. Capacitor product code and its parameters are listed in Table 2.2.

Table 2.2: Selected capacitor and its parameters

|  |  |
| --- | --- |
| Product code | EGXF350ELL751MU15S |
| Datasheet | <http://www.chemi-con.co.jp/cgi-bin/CAT_DB/SEARCH/cat_db_al.cgi?e=e&j=p&pdfname=gxf> |
| Capacitance | 750 µF |
| Voltage-Rated | 35 V |
| ESR | 67 mOhm (@100kHz) |
| Price | $0.81218 |

Selected MOSFET is and its parameters also included in Table 2.3.

Table 2.3: Selected MOSFET and technical properties of it

|  |  |
| --- | --- |
| Product code | FDS5680 |
| Datasheet | <https://www.fairchildsemi.com/datasheets/FD/FDS5680.pdf> |
| Drain-Source Voltage | 60 V |
| Gate-Source Voltage | -+20 V |
| Continuous drain current | 8 A |
| Pulsed drain current | 50 A |
| Power dissipation | 2.5 W |
| Price | $1.86000 |

In our application maximum drain current is 43 A for few milliseconds, thus selected MOSFET meets that requirement too.

Lastly diode product code and its parameters indicated in Table 2.4.

|  |  |
| --- | --- |
| Product code | MBR860MFS |
| Datasheet | <https://www.onsemi.com/pub/Collateral/MBR860MFS-D.PDF> |
| Peak Repetitive Reverse Voltage | 60 V |
| Average forward current | 8 A |
| Peak surge current | 150 A |
| Forward Voltage | 0.8 V |
| Price | $0.80000 |

After selecting all components Buck converter is simulated in Simulink and resulted steady state graphs indicated in Figure Q2.1 and Figure Q2.2.

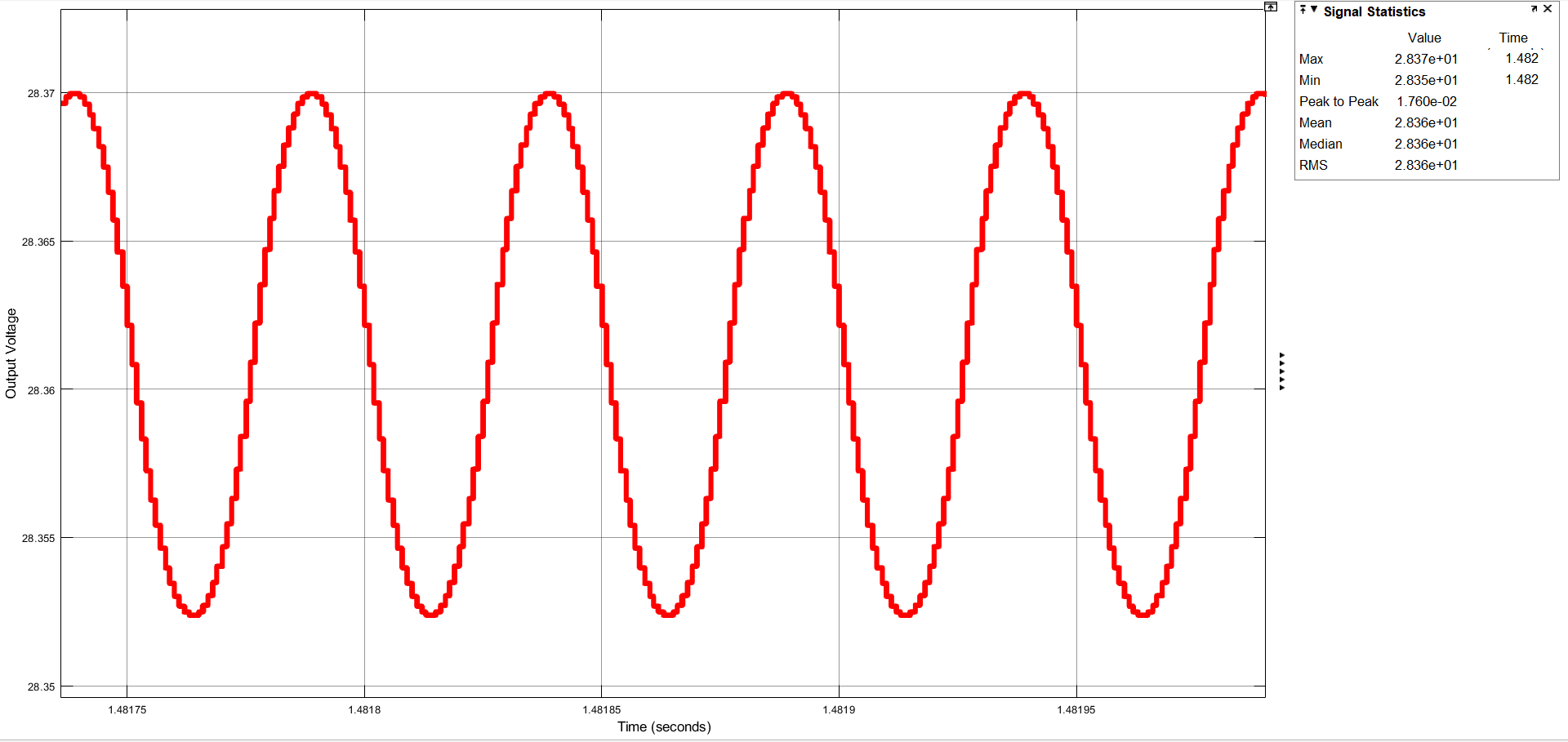


Figure Q2.1: Output voltage at steady state

As seen in Figure Q2.1 ΔVout = 0.0176 V which is low enough for us.

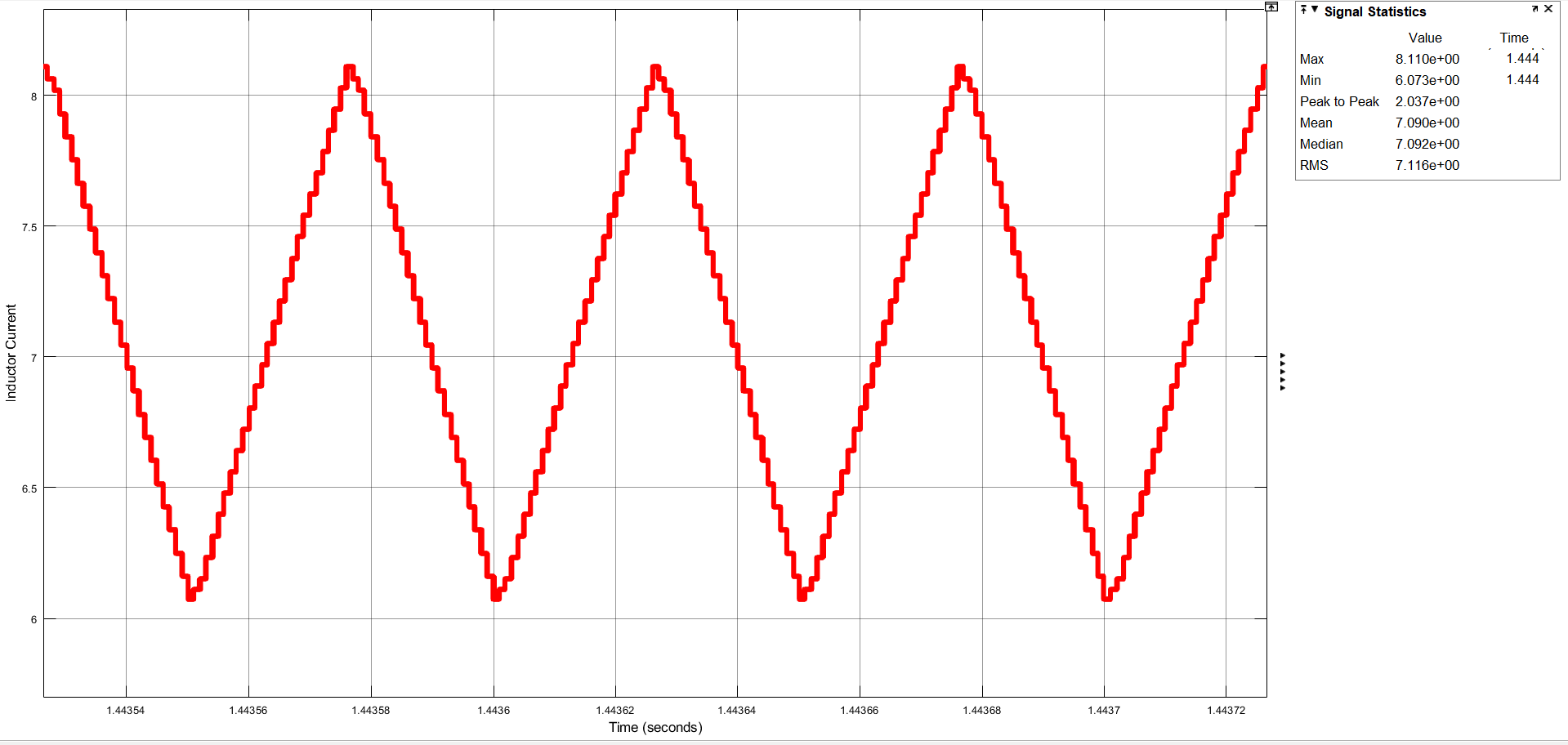


Figure Q2.2: Inductor current at steady state

As seen in Figure Q2.2 ΔIL = 2.037 A which is again low enough for us. Lastly we need to add non-idealities to our converter from components that we selected and then determine the efficiency of the converter. For this after add non-idealities from datasheets of components we found input and output average powers which is shown in Figure Q2.3.

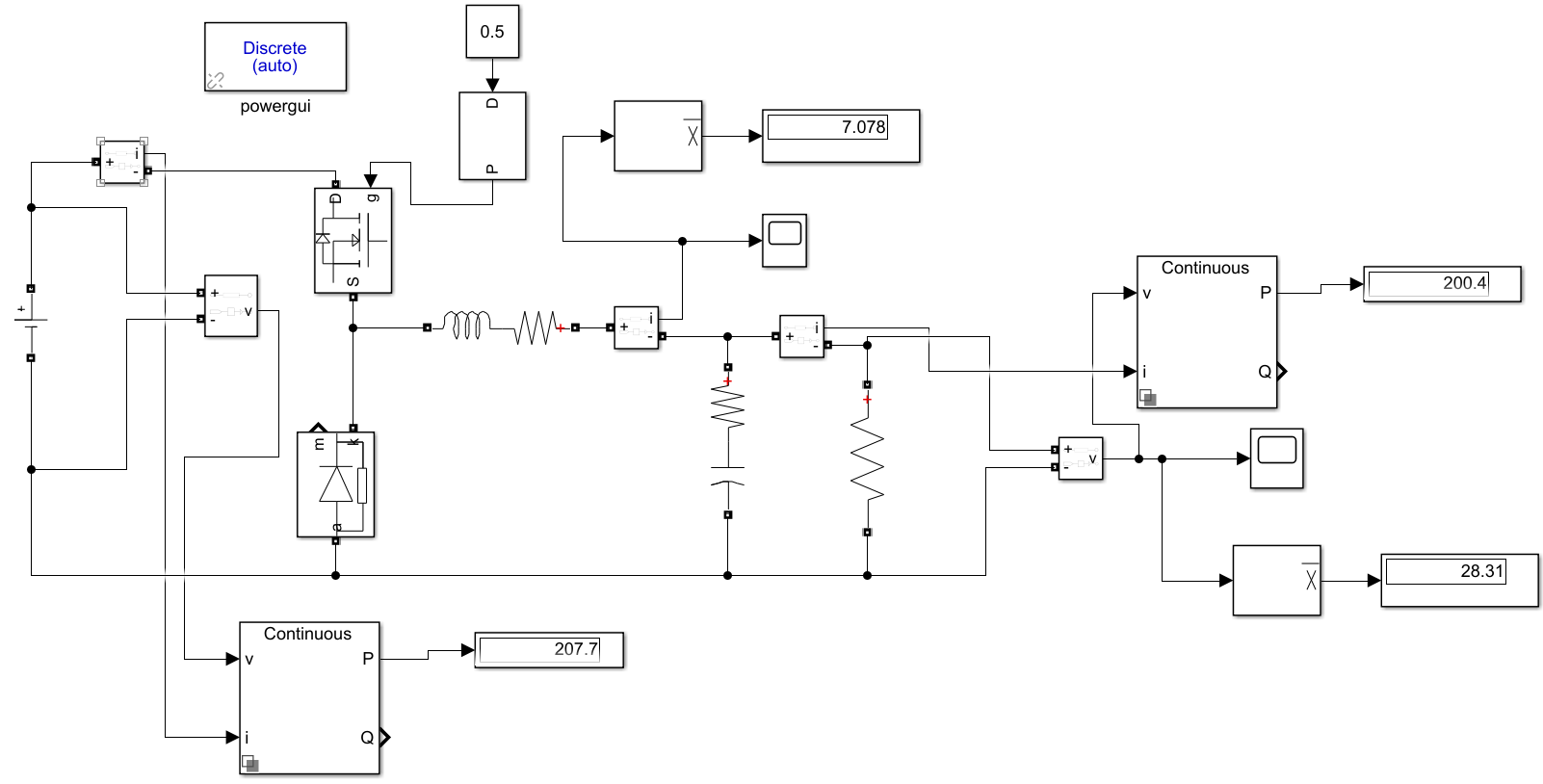


Figure Q2.3: Input and output average powers

From this efficiency of converter = % 96.49

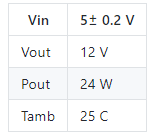
Overall cost = $20.46843

At the end our converter is rather expensive but efficient. Efficiency of converter affected by switching and conduction losses at MOSFET and diode mainly and DCR and ESR values of inductor and capacitor is also effects the efficiency.

## QUESTION 3: Boost Converter (Webench)

In this question we are expected to design a boost converter, whose parameters are given in Table Q3.1, using WEBENCH.

Table Q3.1: Parameters of the step-up converter:



### 3.1) Design Strategy:

We are expected to design a commercial product; therefore, the first consideration should be the BOM cost, which is the cost of comprehensive inventory of the raw materials, assemblies, subassemblies, parts and components, as well as the quantities of each, needed to manufacture a product. [1]. Secondly personally, footprint of the material is a crucial point. Finally, efficiency of the material should be as high as possible. WEBENCH Optimizer in Figure Q3.1, presents 5 optimizing options. Using the order of importance of considerations, we explained above, we chose the second optimizing option as it can be seen from Figure Q3.1 as well.

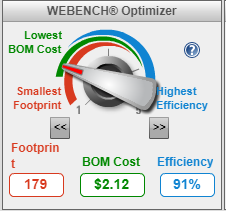


Figure Q3.1: WEBENCH Optimizer

Using the optimizer and input parameters in Table Q3.1, Advance Charting filters converters for us. In Figure Q3.2, Advance Charting plot for our design can be seen, sizes of bubbles correspond to costs of converters, X axis is efficiency and Y axis is footprint. According to the chart, the bubble with the smallest size and closest to right bottom is the optimum converter. This converter is indicated with green. For our design, TPS61088 is selected.

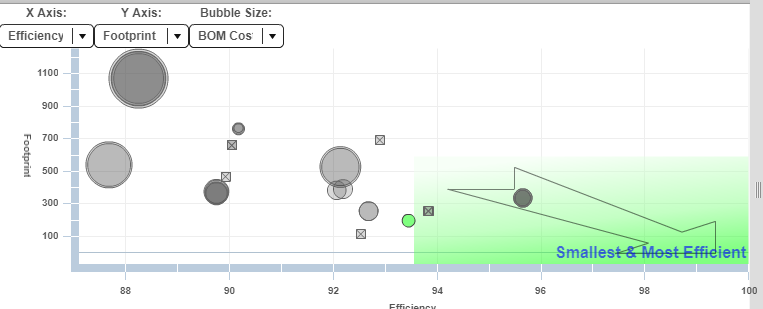


Figure Q3.2: Advance Charting of converters

### 3.2) Most Advantageous Solution: TPS61088

# CONCLUSION

# *References*

[1] https://searcherp.techtarget.com/definition/bill-of-materials-BoM