

MIDDLE EAST TECHNICAL UNIVERSITY

Electrical & Electronics Engineering

Simulation Project #3

EE 463

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# Introduction

In this project, we are asked to design and simulate three phase controlled rectifier which is feeding a DC motor on Simulink. In order to adjust the firing angle of the thyristor rectifier for desired speed, a PI controller is fed back by motor speed into the system. Also, DC/DC converter topologies, namely Buck Converter and Boost Converter, are investigated deeply. Buck converter is designed regarding the commercial products considering the cost, efficiency, ripple etc. of the system. For Boost Converter, Webench digital platform, a Texas Instruments digital tool, is used. The aim of the project is to observe the three phase fully controlled rectifier on controlling a DC motor with a feedback system for adjustable speed and designing DC/DC converters. In this document, related theoretical calculations are illustrated and the simulations are done in Simulink.

# Q1) 3-Phase Thyristor Converter

# Q2) Buck Converter

Aim of the question 2 is designing and simulating a buck converter. Figure 1 shows the schematic of buck converter.

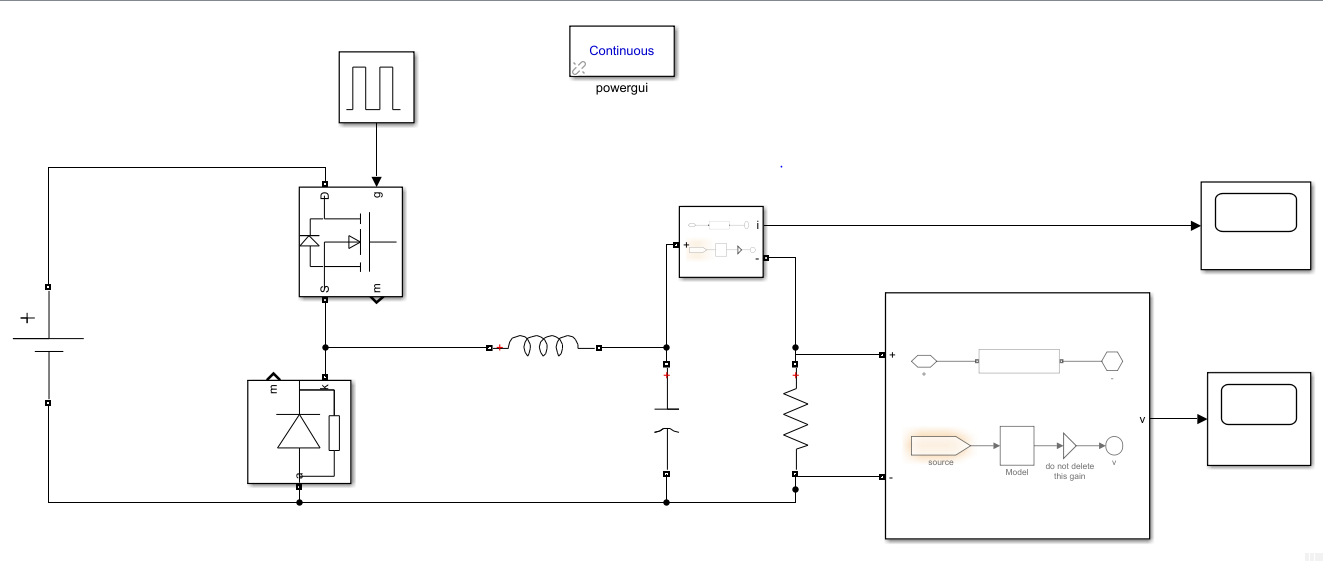


Figure 1: Buck Converter

Input voltage of the converter is 56V. Pulse generator which has 35kHz and %50 duty cycle pulse is connected the gate of MOSFET. Inductor, Capacitor and Resistor values are selected 180µH, 15µF and 4Ω. Ripple current and voltage is founded smaller than 0.1A and 0.3V. Figures 2,3,4 and 5 show the graph of the output current, graph of the output voltage, ripple current and ripple voltage respectively.

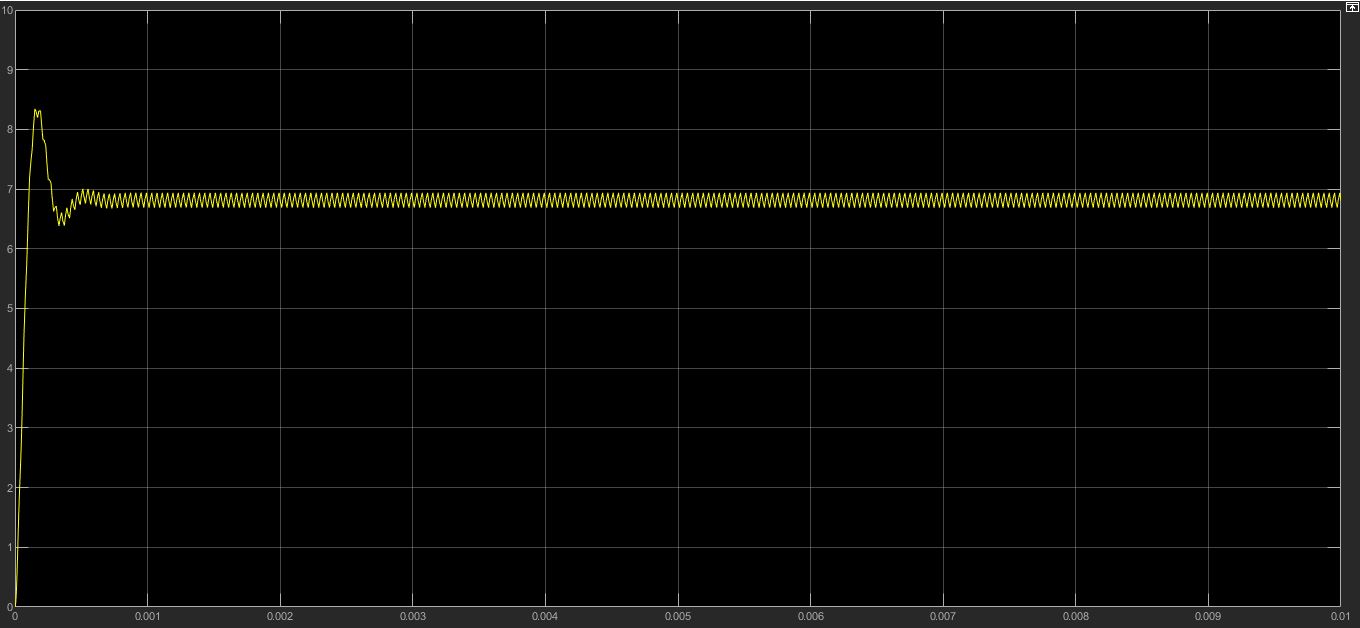


Figure 2: Output Current

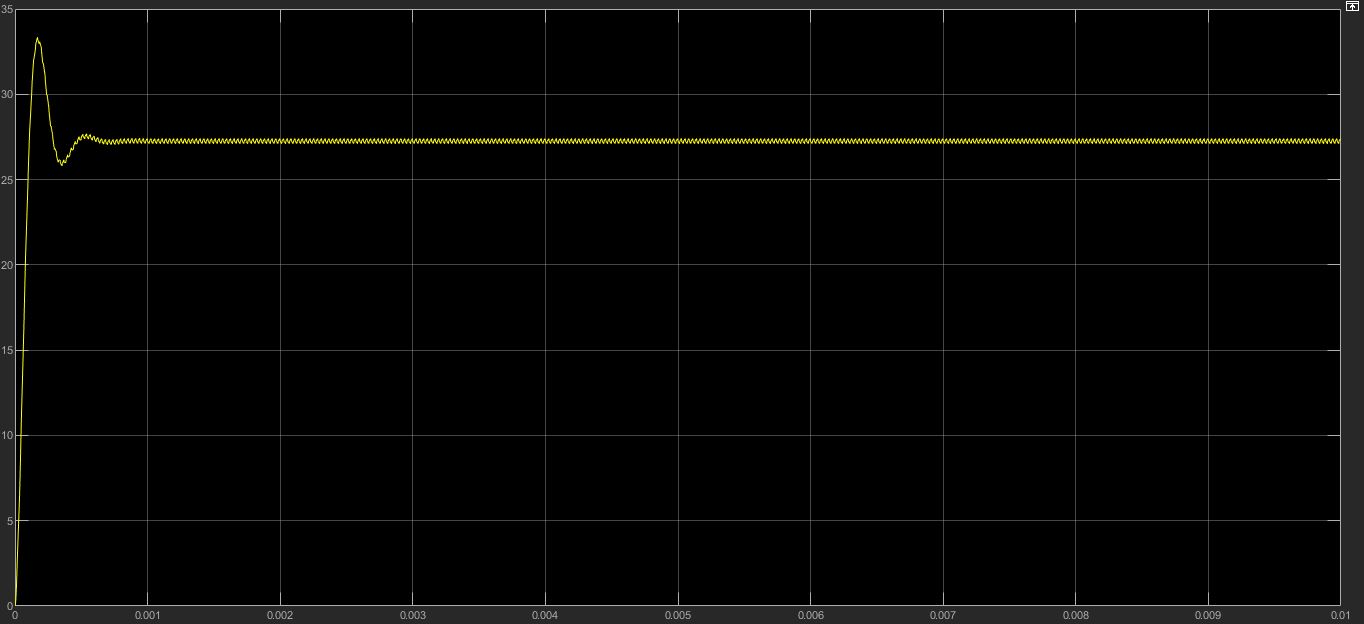


Figure 3: Output Voltage



Figure 4: Ripple Current



Figure 5: Ripple Voltage

Api Delevan’s 180µH inductor is selected because it has 7.28A continuous and 9.86A with saturation current. Its DC resistance is max 45mOhm and its price 8 Dollars. Vishay Sprague’s 15µF capacitor is selected because it has 82mA ripple current for high frequencies. Its price is 6 dollars. Taiwan Semiconductor Corporation’s diode is selected because it has 60Vr and 12A current characteristics. Its price 0.35 dollars. For Mosfet, Micro Commercial Co’s Mosfet is selected because it has 60Vdrainsource voltage and 12A continuous current rating. Its price is 0.87 dollars. Total price is 15.22 Dollars.

The output power is measured 185.5 W as can be seen in the Figure 6.

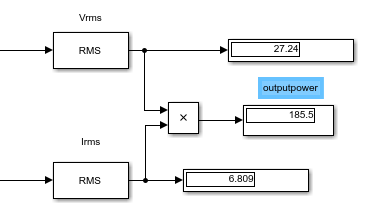


Figure 6: Output Power

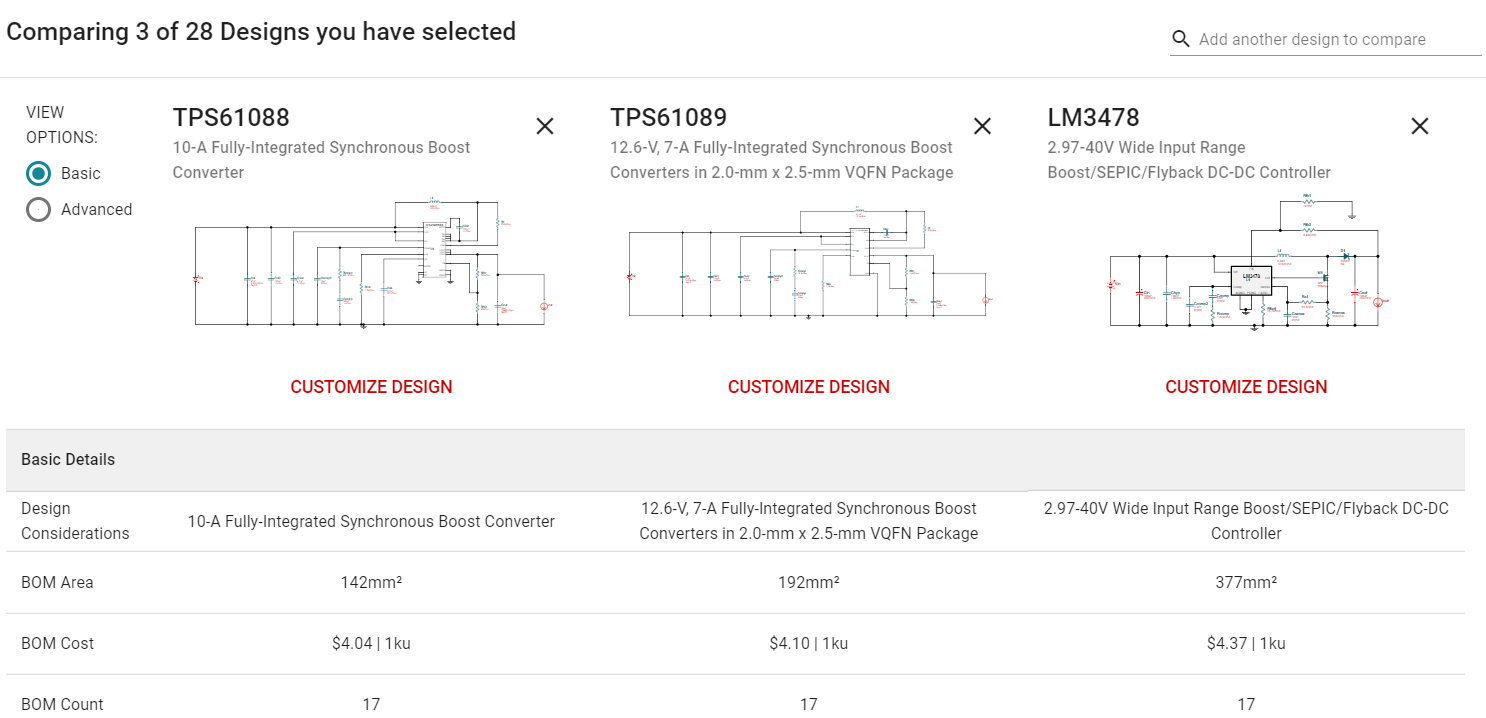
Mosfet has 3W loss according to the its datasheet. 4.6 W is loss because of the diode which is measured from multiplying forward voltage and current passing the diode. The inductor has approximately 4.5 W loss and capacitor loss is ignored. Then total loss is approximately 12.1W. The efficiency is 174.4/185.5=%94. Switching elements cause the loss. If the frequency is decreased efficiency will be increased but ripple will be increased.

# Q3) Boost Converter (Webench)

## 3.1)

Note that all analysis in Q3 are done using Webench [1] digital platform of Texas Instruments.

Since the interface of the Webench has changed, we are not able to compare the topologies via Advanced Charting method. Instead a comparison chart is used for this reason. When the desired input output parameters are implemented into the filters, there are 28 options we face with for boost converters. Looking the big picture, most of the suggestions are controllers for different converter topologies. However, some of them are fully integrated (controller included) converters. Controller integrated IC’s are preferred for simplicity.



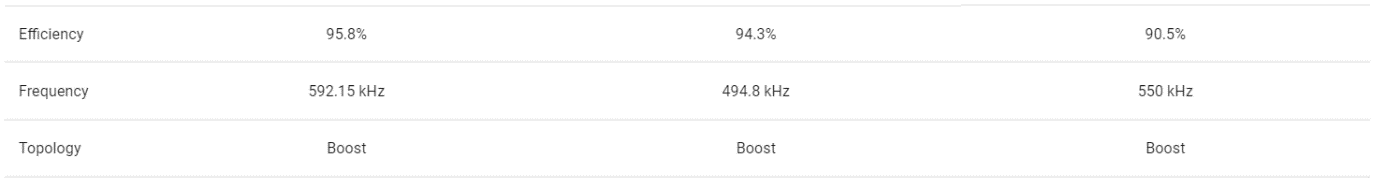


Figure 1: Comparison Chart for 3 different converter IC

Considering efficiency, BOM count, BOM area, frequency range and BOM cost, the best IC is chosen as TPS61088, a fully-integrated Synchronous Boost Converter as shown in Figure 1.

## 3.2)

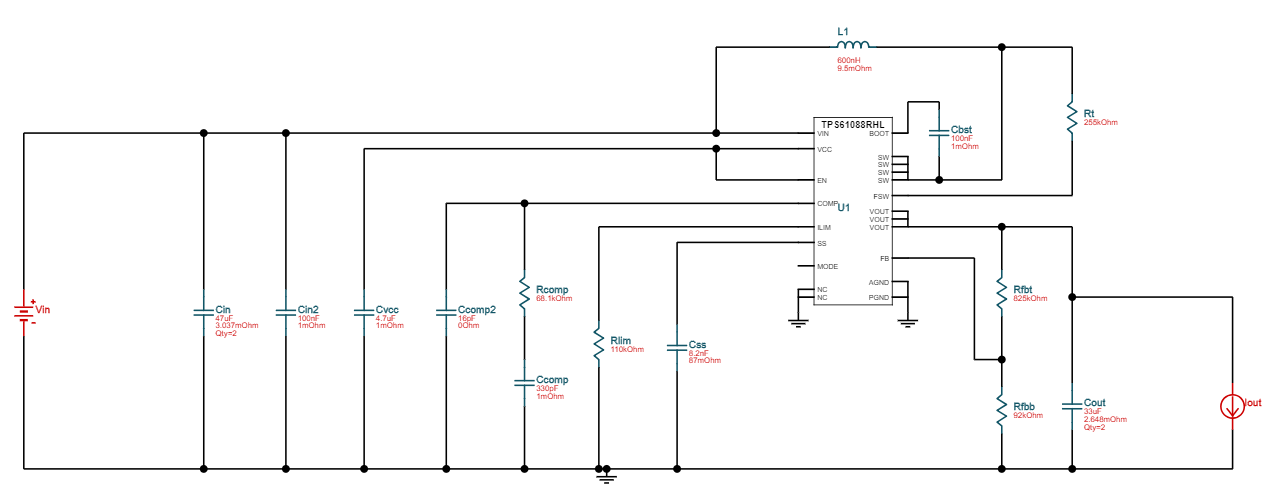


Figure 2: Circuit schematic with TPS61088 IC

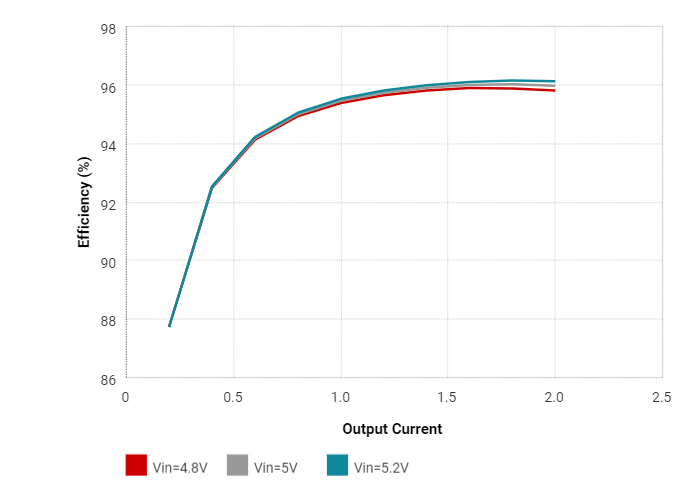


Figure 3: Efficiency vs output current waveform

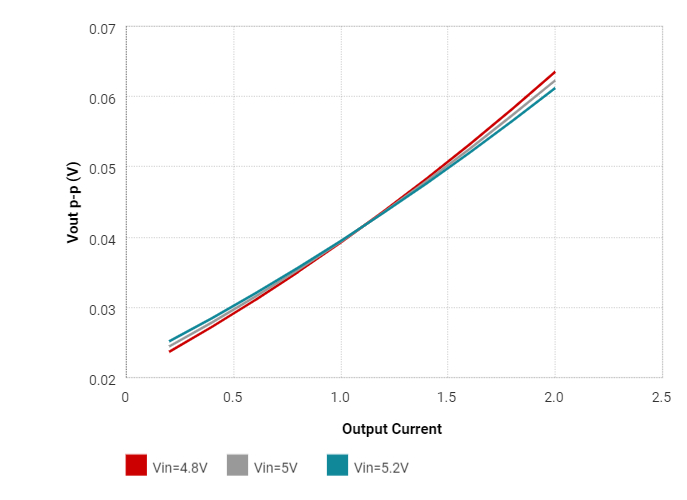


Figure 4: Output voltage ripple vs output current waveform





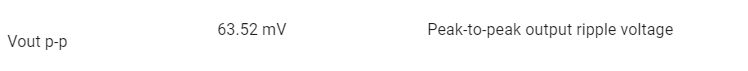












Figure 5: Operation values of designed Boost Converter

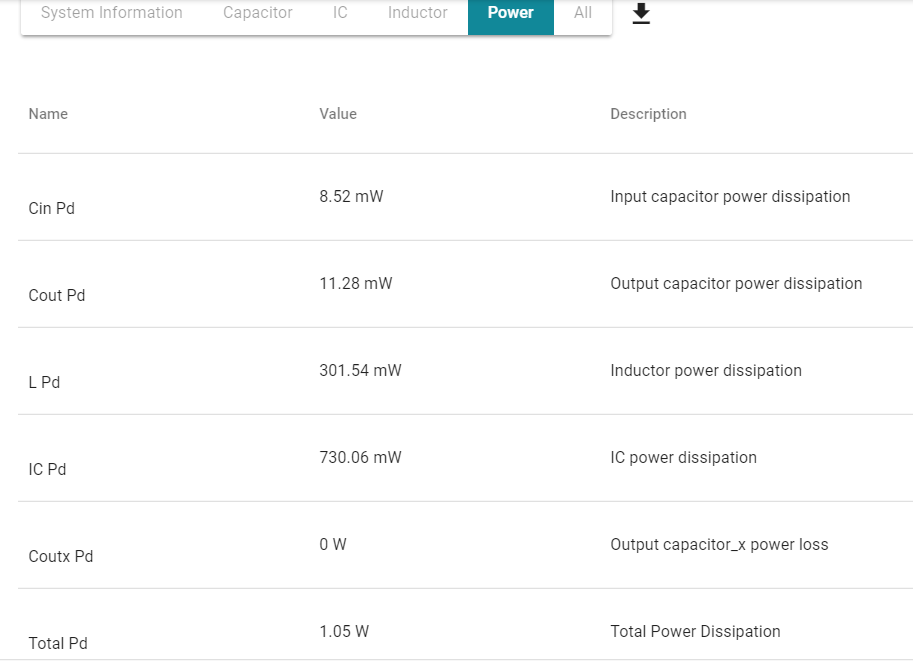
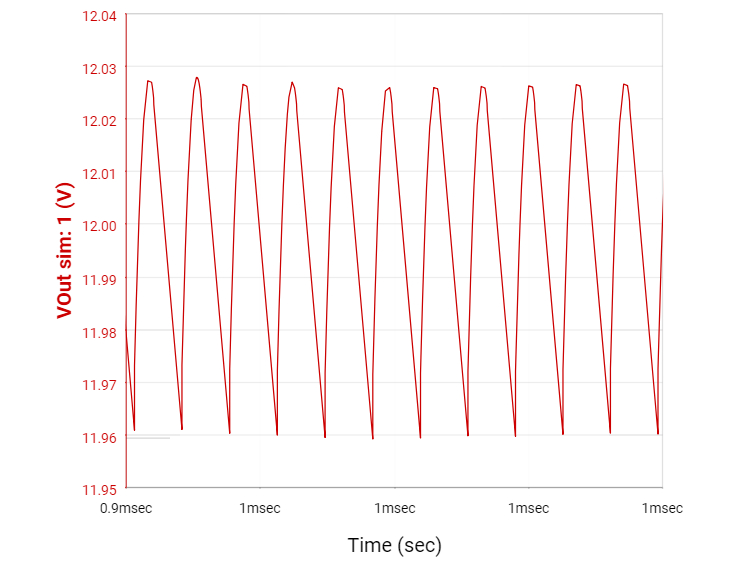


Figure 6: Power dissipation of circuit elements



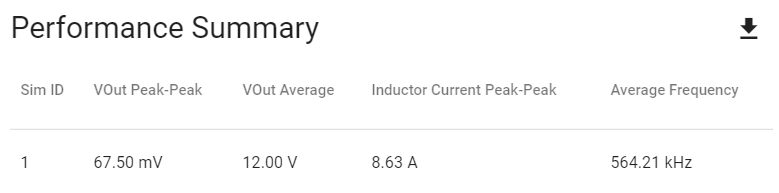


Figure 7: Vout vs Time graph and performance summary at Steady State

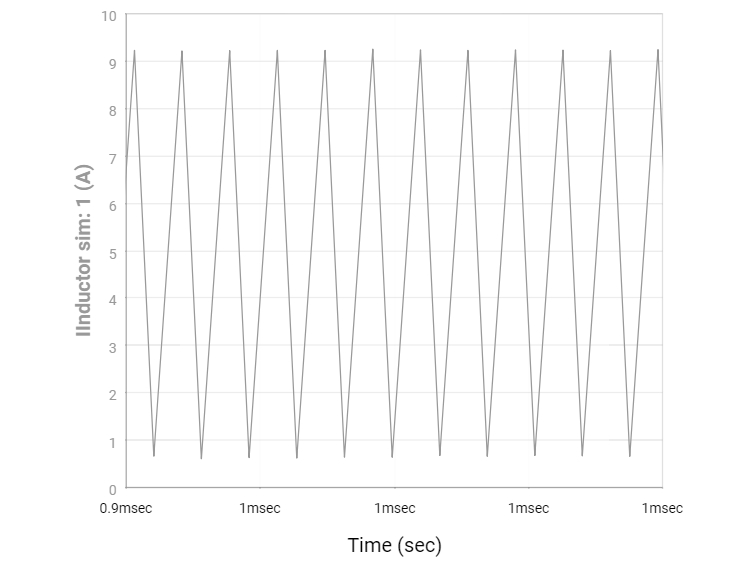
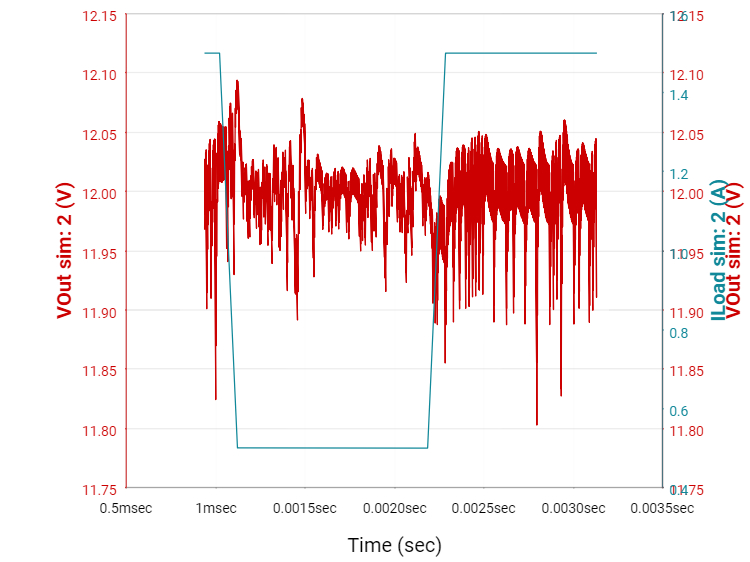


Figure 8: Inductor Current vs Time at Steady State



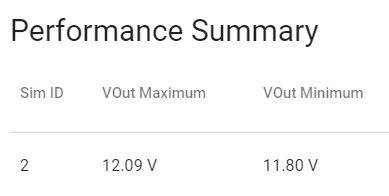


Figure 9: Vout & Iload vs Time graph and performance summary at Transient

### Comments

The desired output voltage is obtained as 12V with small ripple which is less than 0.1V at steady state, 0.83%. Hence, the performance for voltage output is satisfactory. However, inductor current has high ripples which may cause high di/dt problems and thus parasitic voltages in the system. Also, it causes huge loss on the system as 301mW, second in total loss chart after IC power consumption. However, in total we have 1.05W of power loss which is significantly low power dissipation for a converter topology.

Noting the efficiency is about %96, we have excellent efficiency level for input range 4.8V-5.2V. Considering also the BOM cost and footprint, designed boost converter is very logical and advantageous system for applications. Also, thermal characteristics of the system is satisfactory with junction temperature 53°C. We can use this system without a heatsink with this temperature and power dissipation rate.

All in all, the designed Boost Converter works very well for given parameters in the aspects of efficiency, BOM Cost, footprint, thermal characteristics, power dissipation rate, voltage and current characteristics.

# Conclusion

In this document, controlled rectifiers with different topologies are analysed. The effect of firing angles onto output voltage and currents and the resultant effect of THDs and effects are examined. Characteristics for each topology is mathematically derived and explained respectively.

DC motor drive which is fed by 3-phase AC grid, rectified with full-bridge rectifier, is analyzed. Output waveforms are illustrated such as speed, back emf voltage and armature current etc. Two methods, combining capacitor and inductors accordingly, are proposed to reduce the ripple at the output torque which is related with the output current. Power and efficiency calculations are done. They are illustrated in the pie chart.

12-pulse rectifier is analyzed and compared with the full-bridge rectifiers. Advantageous and disadvantageous of 12-pulse rectifier are discussed and compared with the other converter topologies.

# References

[1] *Webench Power Designer*. Retrieved from: https://webench.ti.com/power-designer/

[2] https://www.digikey.com/product-detail/en/api-delevan-inc/DC1390-184K/DC1390-184K-ND/4202759 **(inductor price)**

[3] http://www.delevan.com/seriesPDFs/DC1390.pdf **(inductor datasheet)**

[4] https://www.digikey.com/product-detail/en/vishay-sprague/30D156M040BA6A/30D156M040BA6A-ND/5609488 (**capacitor price)**

[5] http://www.vishay.com/docs/42041/30d.pdf **(capacitor datasheet)**

[6] https://www.digikey.com/product-detail/en/taiwan-semiconductor-corporation/SK12H60-A0G/SK12H60A0G-ND/7376931 **(diode price)**

[7] http://www.taiwansemi.com/products/datasheet/SK12H45%20SERIES\_E13.pdf **(diode datasheet)**

[8] https://www.digikey.com/product-detail/en/micro-commercial-co/MCQ12N06-TP/MCQ12N06-TPMSDKR-ND/9656008 **(mosfet price)**

<http://www.mccsemi.com/up_pdf/MCQ12N06(SOP-8)-A.pdf> (mosfet datasheet)