

**METU**

**ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT**

**EE463 – Static Power Conversion I**

**Fall 2021-2022**

**Term Project Simulation Report**

**Judicator Inc.**

**Hüsnü Oğuz YORGANCILAR**  **23**

**Ece İrem YAZIR**  **23**

**Kaan TÜTEK** **2375954**

**To be submitted to: Assoc. Prof. Ozan KEYSAN**

Table of Contents

[Introduction 3](#_Toc91963159)

[Topology Discussion 3](#_Toc91963160)

[Simulations 3](#_Toc91963161)

[Rectifier 3](#_Toc91963162)

[Buck Converter 3](#_Toc91963163)

[555 Timer 8](#_Toc91963164)

[Overall Circuit 9](#_Toc91963165)

[Component Selection 9](#_Toc91963166)

[Thermal Analysis 9](#_Toc91963167)

[Implementation 9](#_Toc91963168)

[References 10](#_Toc91963169)

# Introduction

# Topology Discussion

# 

# Simulations

## Rectifier

## Buck Converter

With the output of the rectifier fed into the buck converter and the output of the rectifier fed into the DC motor with a terminal voltage limit of 180VDC, the relation between the buck converter input and output demands a careful cap on its main control parameter, the duty cycle. Vs,rms will be assigned 100V as was done in the rectifier simulation.

However, with the addition of an output capacitor, the average output voltage of the rectifier is expected to increase. This increase can be compensated by decreasing the calculated duty cycle. For now, we will limit D at 0.7. This will be monitored with the potentiometers inside the 555 timer topology.

Even so, a duty cycle of 70% could be fatal to the driver circuit during start-up. DC motors have large inrush currents due to the induced emf being speed dependent:

The low speed of the motor, coupled with the low armature resistance of 0.8Ω, can lead to very high currents. Considering we are allowed to soft-start the motor by manipulating D over time, we will start the circuit with a 10% duty cycle and measure the voltage and current maxima displayed over the components. This will help us simulate the worst-case scenario in terms of currents and determine the limiting metrics. We will replicate the DC motor as an RL branch in series with Ea=0.05V.

The buck converter won’t have an LC filter at its output due to the motor acting as an RL load itself. The switching component was selected to be an IGBT due to its superior current-voltage limits. The input was provided as 220VDC.

The frequency of operation was registered in the pulse generator block as 1kHz. The pulse generator represents the 555 timer output.

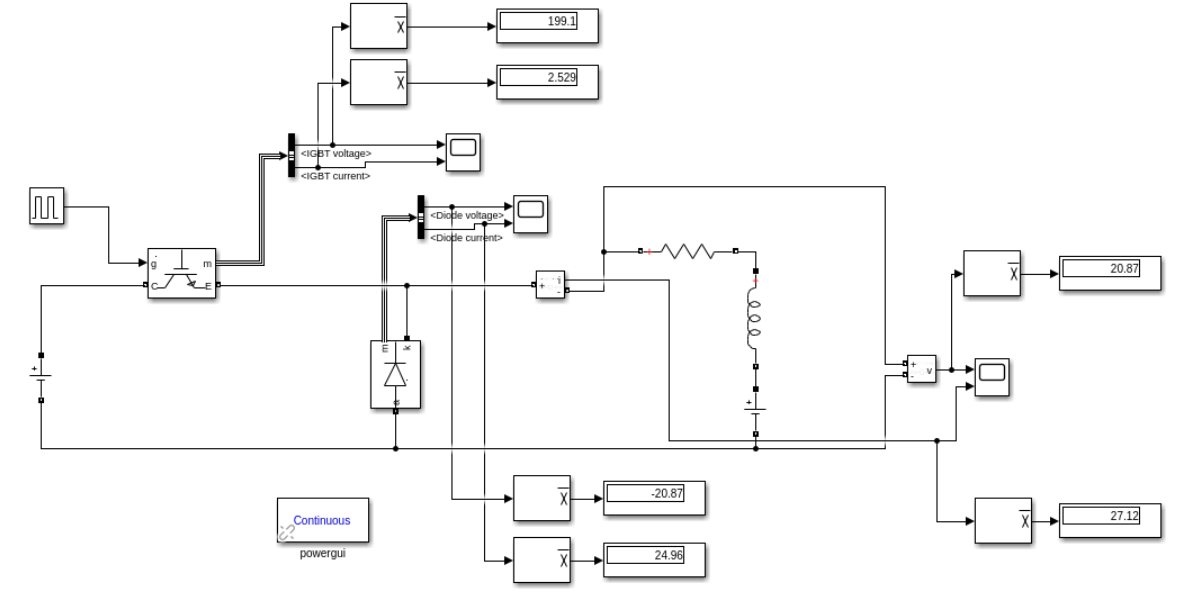


Figure x. Standalone buck converter model at D=0.1 in Simulink.

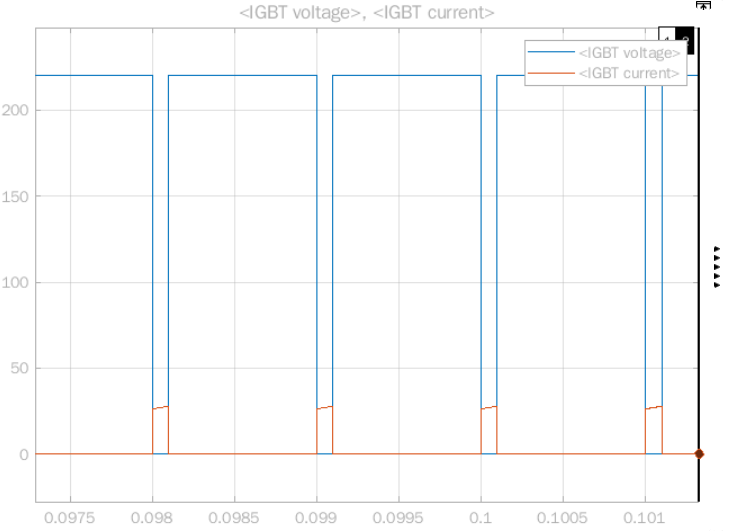


Figure x. IGBT voltage and current waveforms at D=0.1 in Simulink.

An average voltage of 199.1V and an average current of 2.529A was recorded on the IGBT for D=0.1. Considering Vin \* (1-D) is 198V for this duty cycle, the IGBT diode voltage is a value we were expecting. This is because the IGBT voltage is zero during the on period (for an interval of DTs) of the buck converter, and nonzero otherwise.

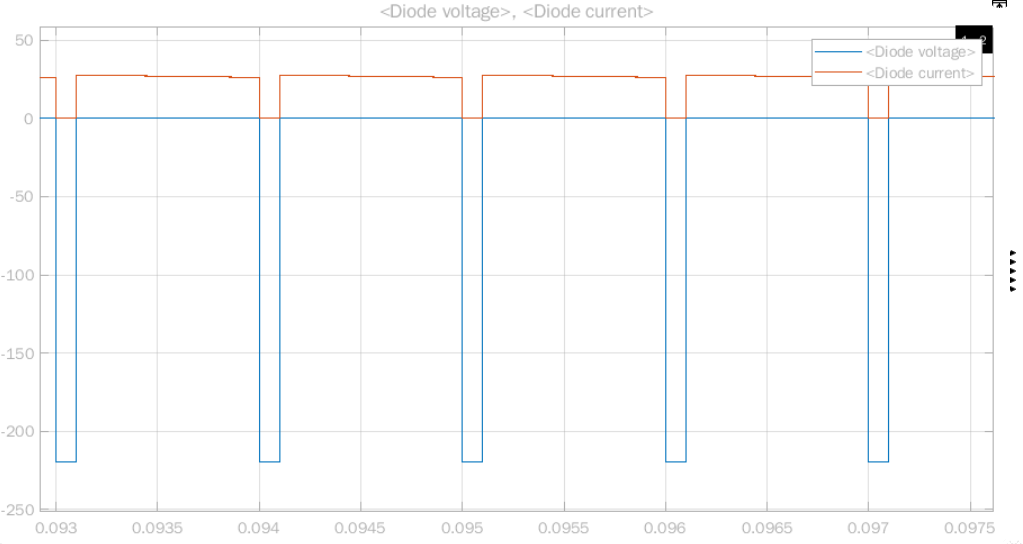


Figure x. Freewheeling diode voltage and current waveforms at D=0.1 in Simulink.

An average voltage of -20.87V and an average current of 24.96A was recorded on the freewheeling diode for D=0.1. Considering Vin \* D is 22V for this duty cycle, the average diode voltage is a value we were expecting. This is because the diode voltage is only zero during the off period (for an interval of (1-D)Ts) of the buck converter, and negative otherwise (reverse-biased).

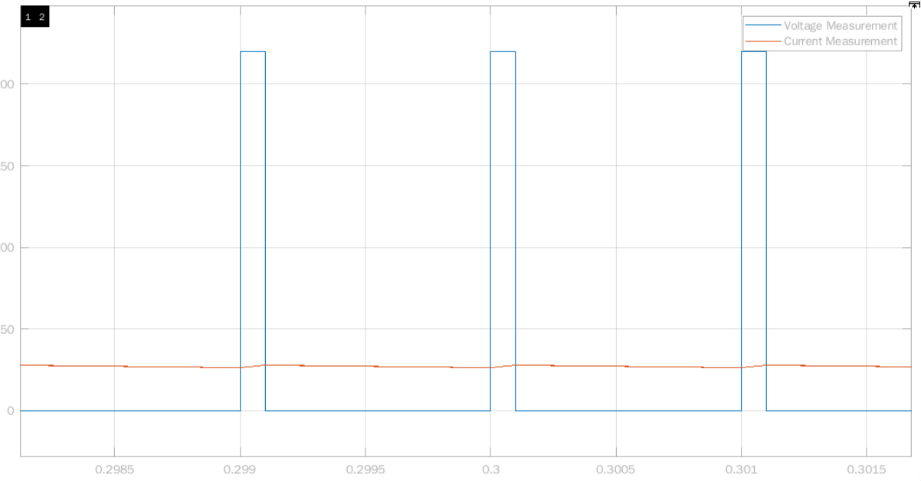


Figure x. Output voltage (Va) and current waveforms (Ia) at D=0.1 in Simulink.

An average voltage of 20.87V and an average current of 27.12A was recorded on the DC motor for D=0.1. Indeed, this is close to the expected output, at DVin = 22V.

Providing a safety margin of +10%, the set of waveforms for D=0.1 place the following constraints:

|  |  |  |
| --- | --- | --- |
|  | Current rating | Voltage rating |
| IGBT | 3A | 210V |
| Freewheeling diode | 30A | -25V |

Figure x. IGBT and diode voltage and current limits for D=0.1 in Simulink.

It is expected that the IGBT current and diode voltage ratings will have to increase for the D=0.7 simulations, with the increase in the on-time of the circuit.,

With the duty increased to 70%, we will assume the motor has now sped up to its rated value of 1500rpm. For Ea, it was assumed that the constant term KaKfIf = 1, meaning Ea is simply the angular frequency counterpart of 1500rpm, at 157.08V.

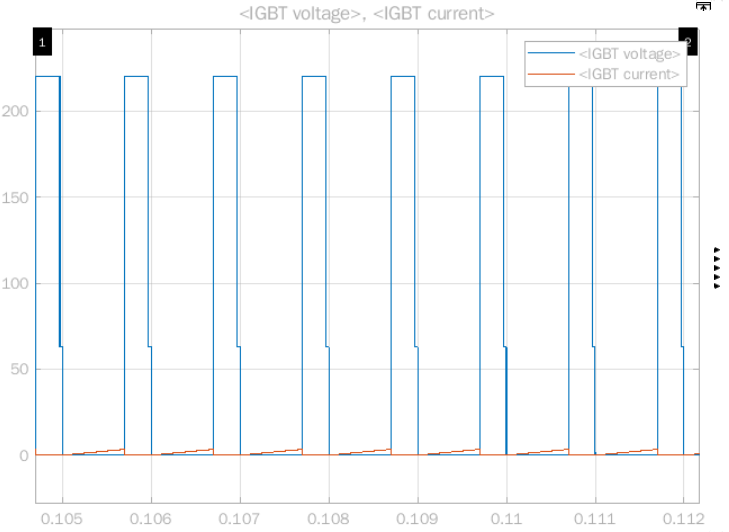


Figure x. IGBT voltage and current waveforms at D=0.7 in Simulink.

An average voltage of 62.81V and an average current of 0.2552A was recorded on the IGBT for D=0.7. Considering Vin \* (1-D) is 66V for this duty cycle, the IGBT diode voltage is a value we were expecting. This is because the IGBT voltage is zero during the on period (for an interval of DTs) of the buck converter, and nonzero otherwise.

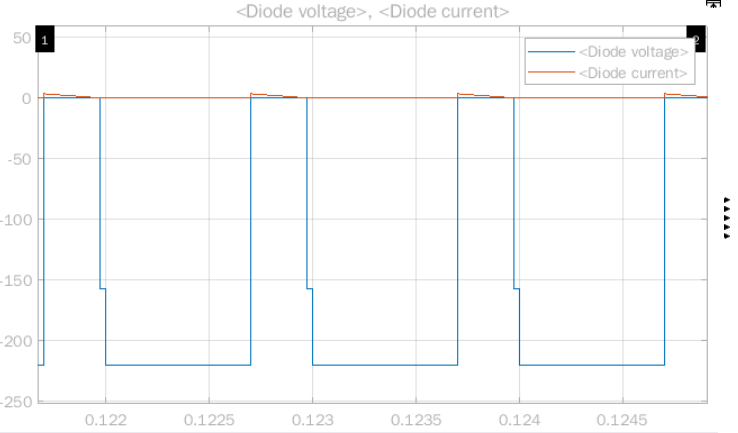


Figure x. Freewheeling diode voltage and current waveforms at D=0.7 in Simulink.

An average voltage of –157.2V and an average current of 0.9553A was recorded on the freewheeling diode for D=0.7. Considering Vin \* D is 154V for this duty cycle, the average diode voltage is a value we were expecting. This is because the diode voltage is only zero during the off period (for an interval of (1-D)Ts) of the buck converter, and negative otherwise (reverse-biased).

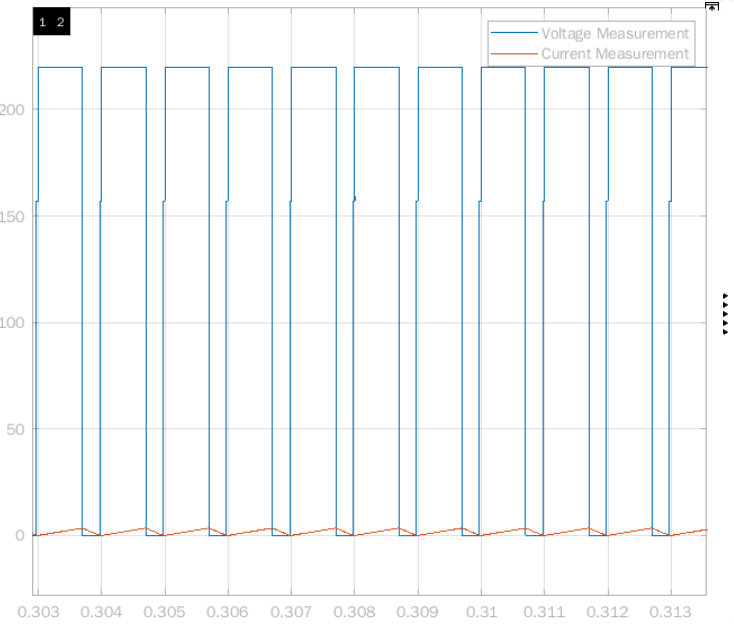


Figure x. Output voltage (Va) and current waveforms (Ia) at D=0.7 in Simulink.

An average voltage of 157.2V and an average current of 1.687A was recorded on the DC motor for D=0.7. Indeed, this is close to the expected output, at DVin = 154V.

The set of waveforms for D=0.7 place the following constraints:

|  |  |  |
| --- | --- | --- |
|  | Current rating | Voltage rating |
| IGBT | 0.5A | 65V |
| Freewheeling diode | 1A | -160V |

Figure x. IGBT and diode voltage and current limits for D=0.7 in Simulink.

Presumably due to the assumption made on the motor emf constants, the armature current appears quite low. Naturally this affects the IGBT and diode currents. This seeming low current limit need not compromise our component selection, since the relatively worse-case scenario was already simulated for start-up conditions.

Taking the maximum ratings for the IGBT and the freewheeling diode for both of the simulated cases,

|  |  |  |
| --- | --- | --- |
|  | Current rating | Voltage rating |
| IGBT | 3A | 210V |
| Freewheeling diode | 30A | -160V |

Figure x. Anticipated IGBT and diode voltage and current limits.

## 555 Timer

To generate a square wave with varying duty cycles to drive the IGBT, we used a 555 Timer.

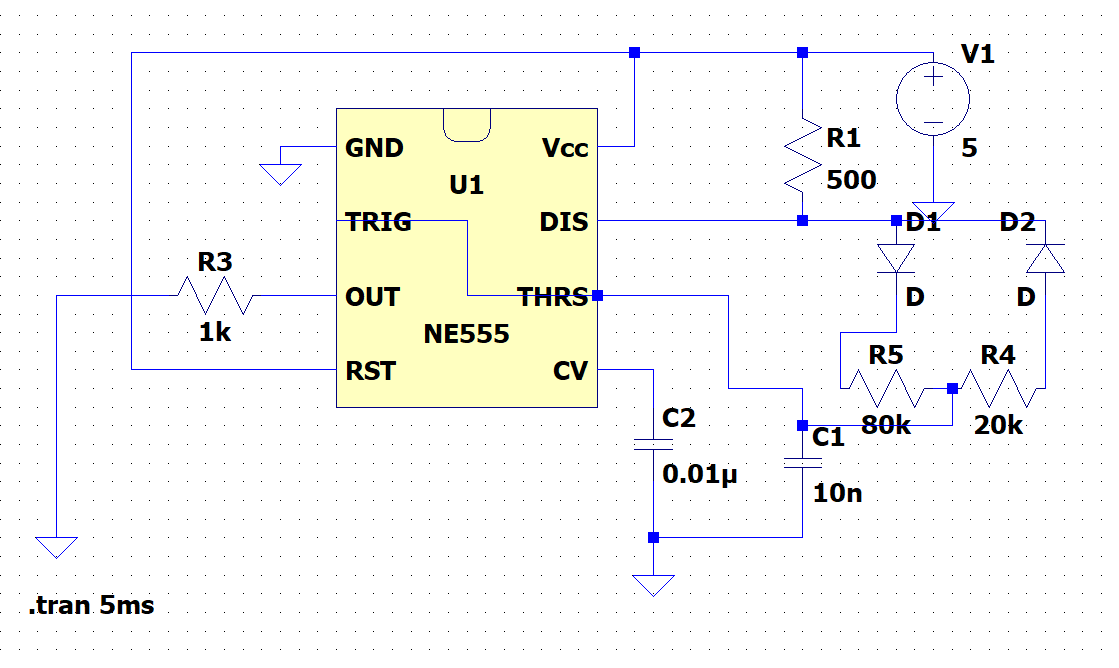


Figure x. 555 Timer schematic on LTSpice.

Here, there are certain parameters that needed to be taken into account. [1]

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Formula** | **Unit** |
| thigh |  | s |
| tlow |  | s |
| Period (T) |  | s |
| Frequency (f) |  | Hz |
| Duty cycle (D) |  | % |

Table x. 555 Timer parameters.



Figure x. 555 Timer output, D=0.2.

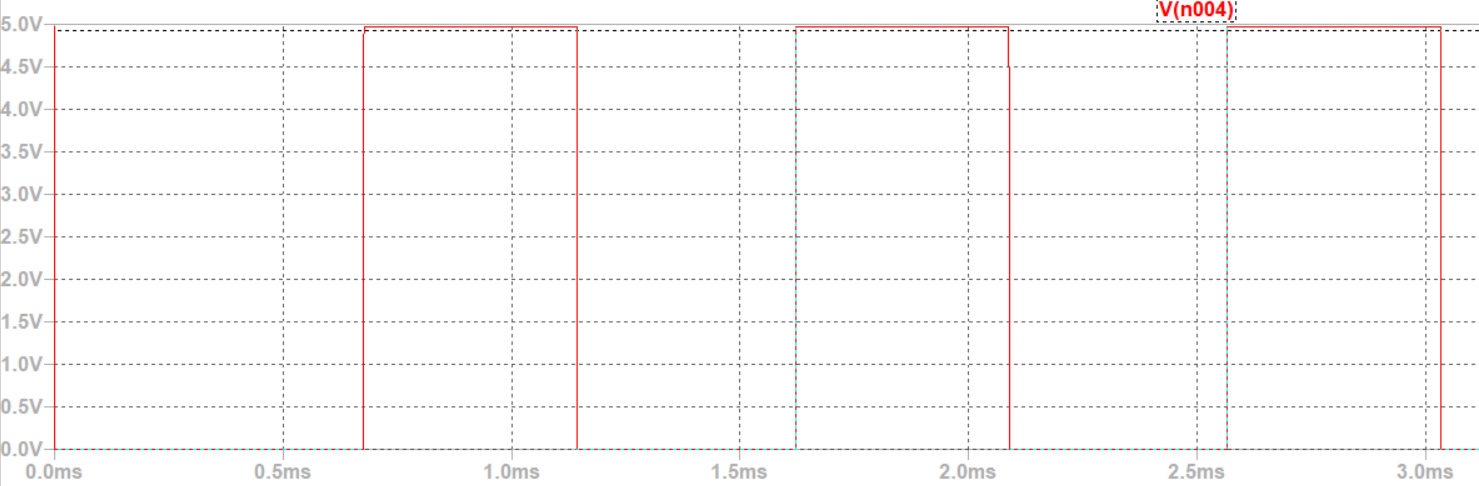


Figure x. 555 Timer output, D=0.5.

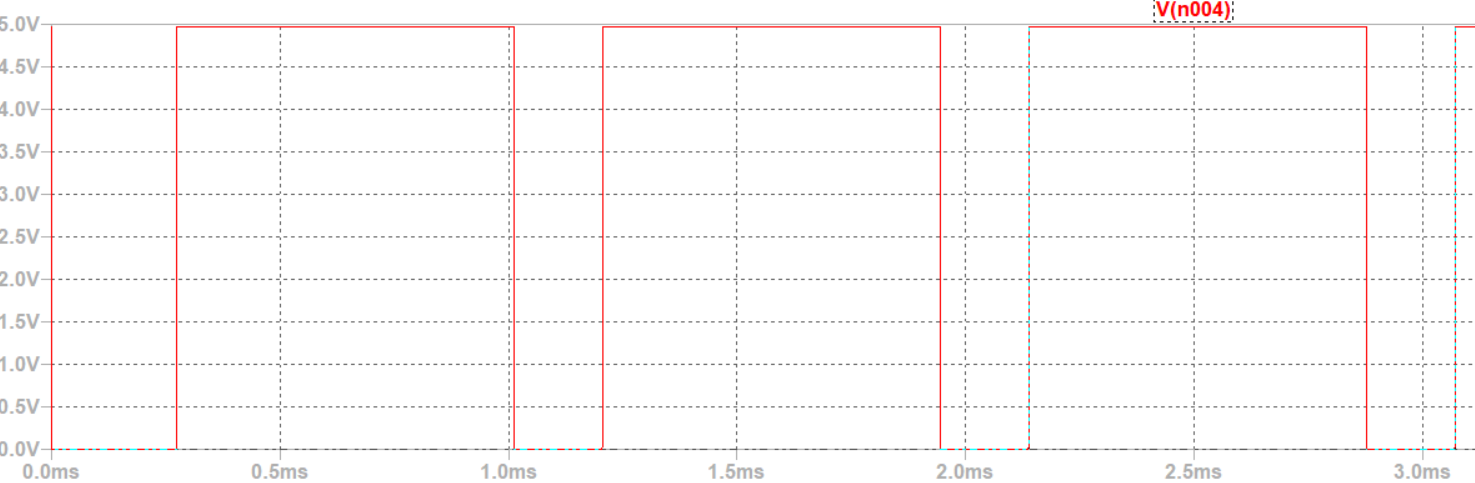


Figure x. 555 Timer output, D=0.8.

There are frequency deviations of ±50Hz due to the exact calibration of 1kHz being difficult to maintain across varying duty cycles. However, considering the maximum 5% deviation from the desired 1kHz frequency, these changes were ignored.

## Overall Circuit

# Component Selection

# Thermal Analysis

# Implementation

So far, we have implemented the three-phase rectifier topology alongside its input ports without the output capacitor on a pertinax. Ohmic losses in this setup were quite high, to the point that one third of the expected average output voltage was already dissipated on the diodes and the solder iron connections or the electric wires. An example oscilloscope trace can be seen below.

This problem is expected to be solved upon the placement of the filter capacitor at the end. Should a single 470µF fail to decrease the ripple (and therefore increase the average voltage) to a desired and relatively steady value, another will be connected in parallel with it.

We will continue with the construction of the PWM generator circuit to drive the IGBT and the optocoupler topology. By using an isolated DC-DC converter to feed the 555 Timer and the optocoupler simultaneously, we will limit the required external DC power sources in the motor drive to a single supply.

Finally, we hope to complete the initial prototype of the circuit with the addition of an LC filter-deprived buck converter. A high side or low side drive method will be used in the IGBT activation. Depending on the verdict, the gate driver topology might change structurally.

# References

[1] 555 Timer Astable Circuit Calculator. <https://circuitdigest.com/calculators/555-timer-astable-circuit-calculator>