TÉCNICO LISBOA

Circuit Theory and Electronics Fundamentals

T3 Laboratory Report

Aerospace Engineering, Técnico, University of Lisbon

May 13, 2021

Group 61

Guilherme Coelho, No. 95794
João Barbara, No. 95809
João Félix, No. 97238

Contents

1 Introduction

The objective of this laboratory assignment was to create a circuit that would transform an input AC voltage of amplitude 230V and frequency of 50 Hz to an output DC voltage of amplitude 12V and frequency 50Hz. To do this, an Envelope Detector, a Voltage Regulator and a Transformer were used. This last component was not actually modeled in the simulation and theoretical analysis. It was considerared that the transformer would be represented with an alternated, independent voltage source that would connect to the envelope detector and would reduce the input amplitude of 230V by a ratio of n:1. This ratio will be decided during the simulation and theorethical analysis. Do note that n can be any rational number, as a large number of coils are used in any real transformer, thus allowing for a great deal of freedom in choosing the transformer ratio.

The circuit is shown below in figure (Fig.1):

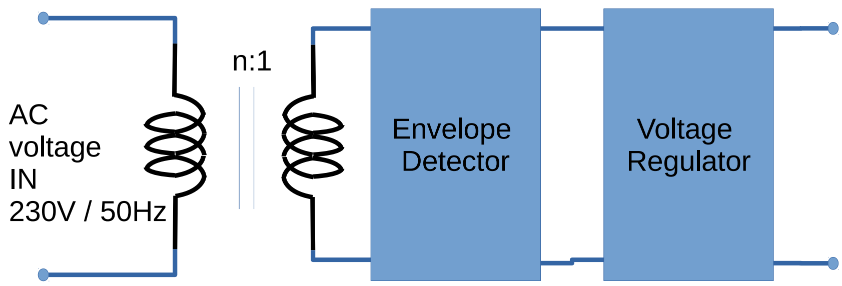

Figure 1: AC to DC converter

To determine the quality of the circuit, when compared to others, a merit classification system was created. This merit system took into account the cost of the components used, as well as the ripple and average amplitude of the output voltage. The merit of the circuit will determined according to the following equation:

$$MERIT = \frac{1}{cost * (ripple_{reg} + |average_{reg} - 12| + 10^{-6})} \quad (1)$$

and the cost of the componets are the following: cost of resistors = 1 monetary unit (MU) per kOhm, cost of capacitors = 1 MU/uF and cost of diodes = 0.1 MU per diode. The voltage source that represents the transformer was not taken into account in the cost, and so the parameter n was regarded as a ”free” parameter.

In Section 3, a theoretical analysis of the circuit is presented. Here the circuit is analised using suitable theoretical models for the diodes, in order to predict the output of the Envelope Detector and Voltage Regulator circuits. The output DC level and the voltage ripple are calculated and the plots for the voltages at the output of the Envelope Detector and Voltage Regulator circuits are presented, as well as the plot for the output deviation (output voltage subtracted by a factor of 12), of the output of the regulator. In Section 2, the circuit is analysed by simulation using the program Ngspice. In Ngspice the default model for the diode was used. The AC/DC converter was simulated for 10 periods and the voltage average and ripple were measured using built in functions of the program. The same plots produced in the theoretical analysis were made in this section, here by simulation. The conclusions of this study are outlined in Section 4, where the theoretical results obtained in Section 3 are compared to the simulation results obtained in Section 2.

2 Simulation analysis

2.1 Simulating the AC/DC converter for 10 periods

The first step to this laboratory assignment was to make a simulation of a simple AC/DC converter in NGSpice. The circuit uses an ideal transformer, using a current controlled voltage source as well as a voltage controlled current source, and also an envelope detector and a voltage regulator.

Altough, because od the fact that the ideal transformer creates a new voltage and current with the same frequency as the original, instead of controlled sources, a simple sinusoidal voltage source would be enough. A simulation of the AC/DC converter was done for 10 periods and all the analysis were made measuring on a $5e-5$ step with the objective of evaluating at least 1000 points during the 10 periods. The frequency of the AC sourcec was used to know the period and then multiplied by 10 with the goal of getting the total time, in order to be able to calculate this step. After that we divided the total time by 1000 points and made the step even smaller than that with the goal of making sure it had more than 1000 points but not too small so that the program ran poorly.

2.2 Output voltage level

We used NGSpice to measure the average output voltage and using a transient analysis we plotted both the average and the signal of the output voltage in the same graph.

Name	**Value [V]**
mean(v(n5)-v(n3))	1.199717e+01

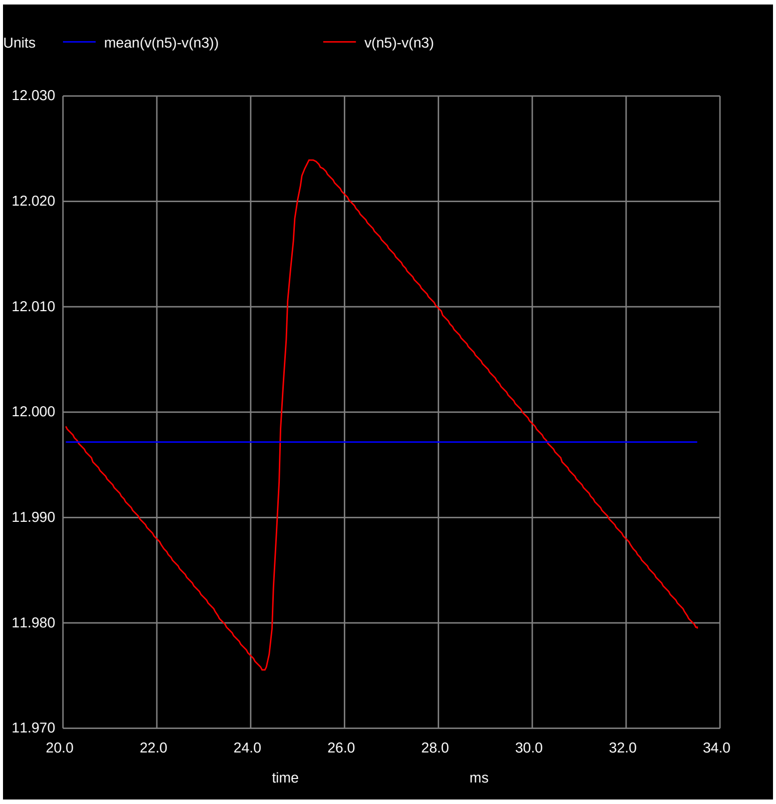

Figure 2: Plot of the average and the signal of the Output Voltage.

2.3 Output of the Envelope Detector and voltage Regulator circuits

The output voltages of the Envelope Detector and the Voltage Regulator circuits were plotted and put each in a different graph as well as a graph with both voltages plotted.

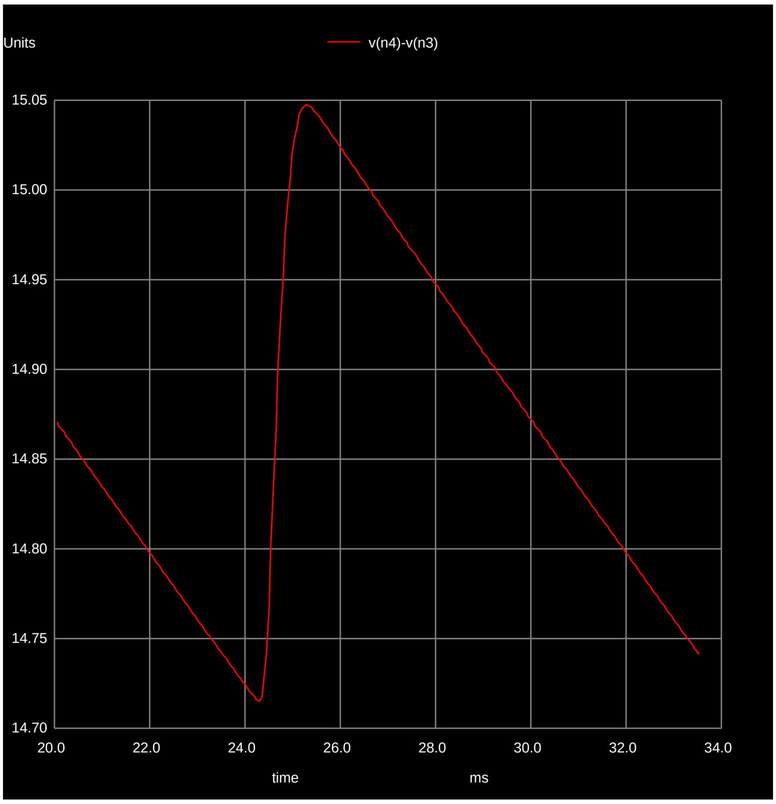

Figure 3: Envelope Detector Output Voltage.

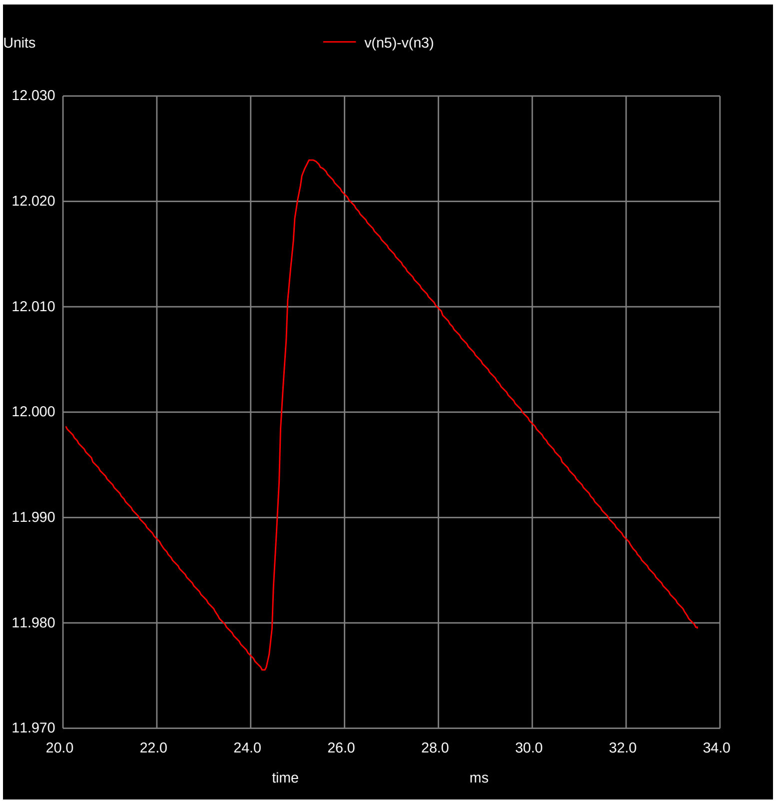

Figure 4: Voltage Regulator Output Voltage.

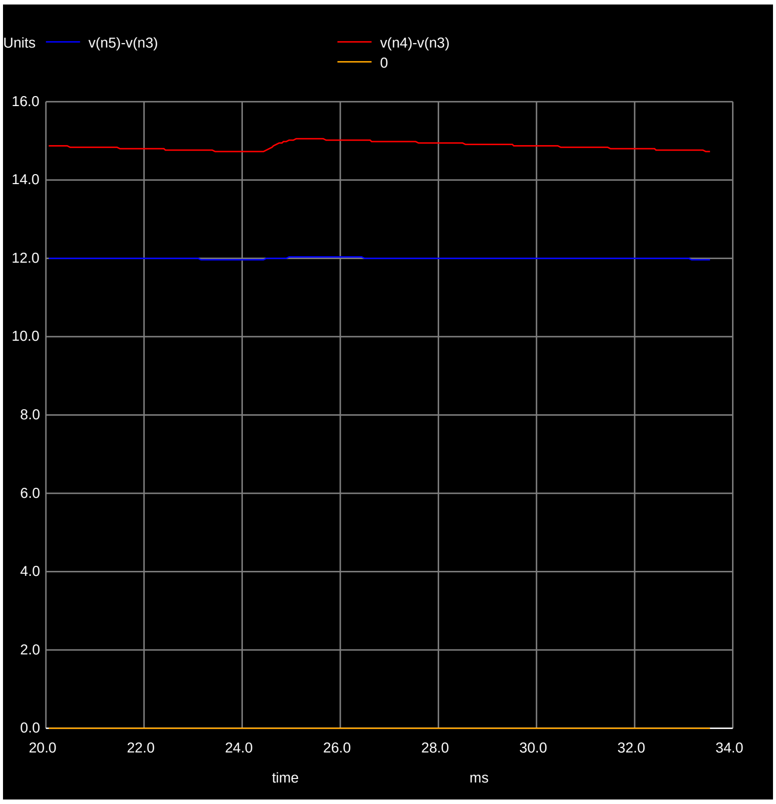

Figure 5: Envelope Detector and Voltage Regulator Output Voltages.

2.4 Output voltage ripple

We then used NGSpice to measure the output voltage ripple, that is the difference between the maximum and the minimum values of the signal.

Name	**Value [V]**
maximum(v(n5)-v(n3))-minimum(v(n5)-v(n3))	4.842582e-02

2.5 $v_0 - 12$ plot

We plotted $v_0 - 12$, which is the output AC component plus the DC deviation, and calculated the deviation, using the mean value.

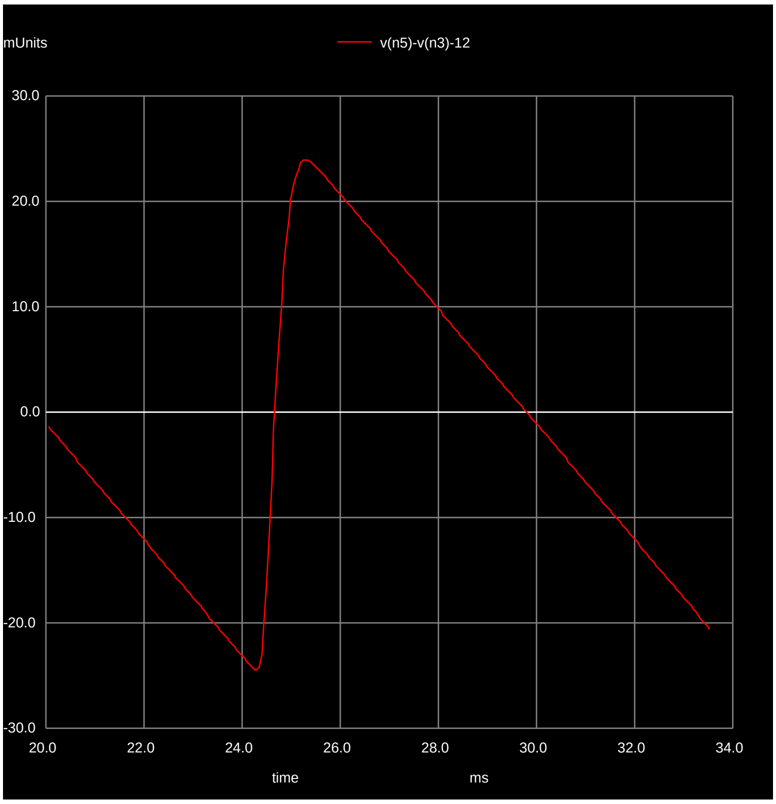

Figure 6: Output AC component + DC deviation.

Name	**Value [V]**
mean(v(n5)-v(n3)-12)	-2.82719e-03

3 Theoretical Analysis

In the theoretical analyses we apply Kirchoff's Laws and diodes equatins to calculate the obtained results. It's important to differ the Evelope Detector (whose function is to restrict voltage's amplitude) from the Voltage Regulator (whose purpose is to decrease the ripple).

3.1 Envelope detector

The envelope detector is composed of a resistance and capacitor in parallel. It decreases the ripple according to the following expression:

$$v_0(t) = Acos(\omega t_{off})^{\frac{-t+t_{off}}{RC}} \tag{2}$$

Where:

- A - Amplitude
- ω - angular frequency
- R - Resistance, constant obtained using the following expression:

$$R = R_3 + rd_n \tag{3}$$

- R_3 - Resistence in serie
- rd_n - Resistence in all diodes, wich currespondes to 23*r_d (the resistance in each diode)
- C - Capacitance
- t_{off} - Constant obtained using the following expression:

$$t_{off} = \frac{1}{\omega} arctan(\frac{1}{\omega RC}) \tag{4}$$

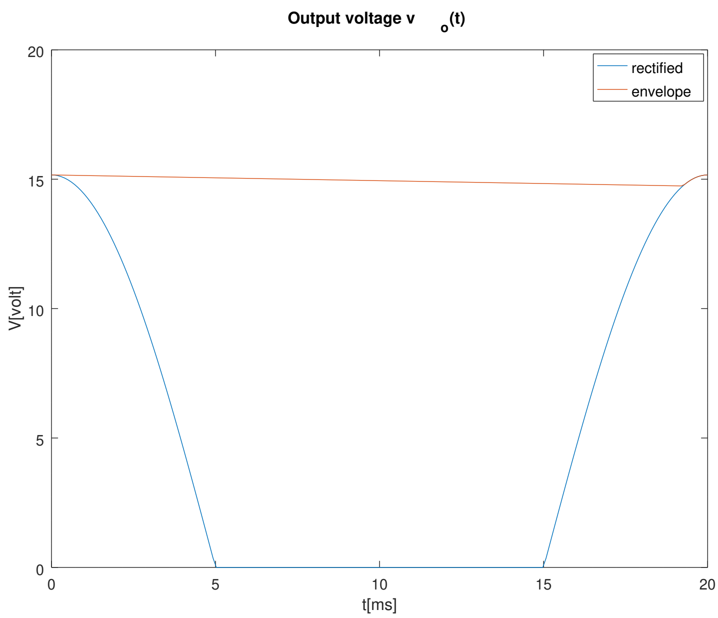

Figure 7: Rectified Signal.

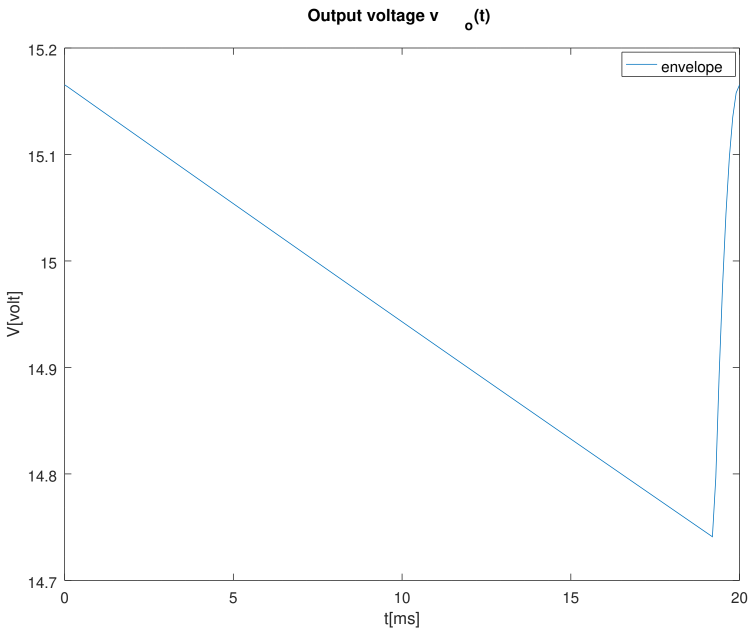

Figure 8: Envelope Detector Output Voltage.

3.2 Voltage Regulator

The voltage regulator is composed by 19 diodes in series that will impose the 12V voltage. The resistance in series will decrease the amplitude.

The expressions used to do this were the following ones:

Sinusoidal part from envelope:

$$v_{sr} = v_O - V_s \tag{5}$$

And then, we have:

$$vO_r = (\frac{rd_n}{rd_n + R_3})v_{sr} \tag{6}$$

The expression used to obtain the vltage ripple was:

$$v_{ripple} = maximum(V_{dc}) - minimum(V_{dc}) \tag{7}$$

Where:

$$V_{dc} = 21V_{on} + vO_r \tag{8}$$

The results are shown below:

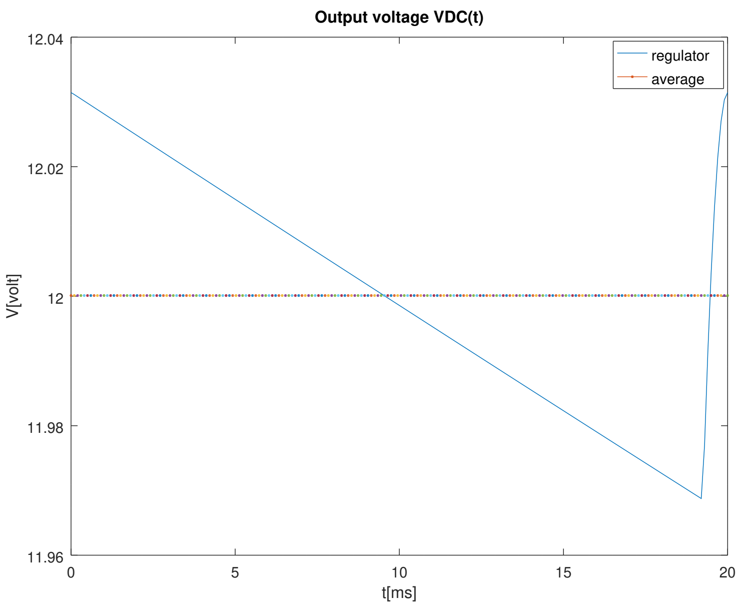

Figure 9: DC Output Signal.

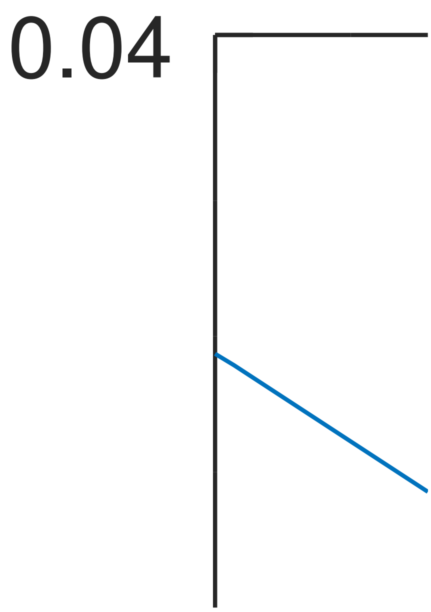

Figure 10: Output Signal - 12 (deviation).

Name	Value [V]
Ripple	6.269596e-02

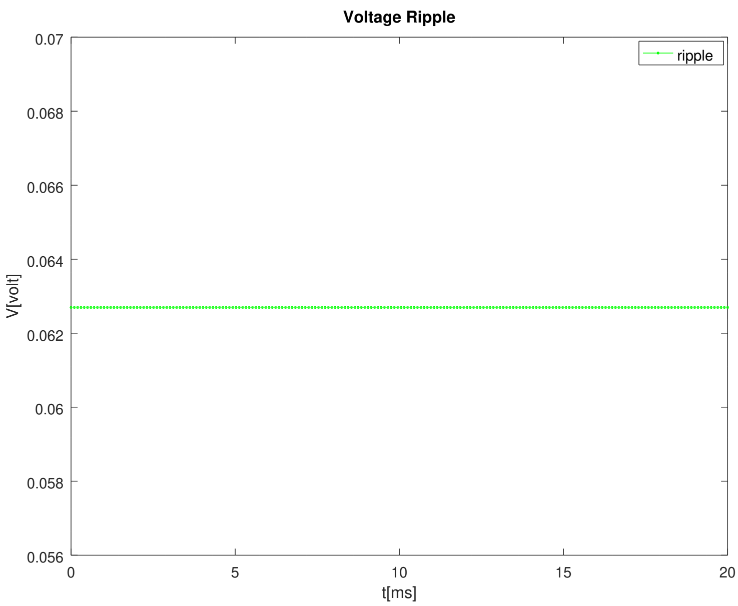

Figure 11: Ripple.

4 Conclusion

This laboratory assignment had the purpose of building a circuit which could transform an AC input of 230V voltage and 50HZ frequency into an output of 12V with the minimum cost and ripple. This objective has been sucessufuly achieved.

This project provided us the opportunity to understand how the envelope detector and voltage regulator circuits work and also, how to improve their efficieny. We're also able to analyse carefully the working principle of an AC/DC converter.

In order to analyse the circuit theoreticaly *Ocatve* was used as well as all the Kirchoff's equations and diode models that support this analysis. The simulation was done using *Ngspice*.

The final value for the Merit obtained was 0.26.

Name	**Value**
Resistor Cost	3.315000e+01
Capacitor Cost	2.600000e+01
Diode Cost	2.300000e+00
Total Cost	6.145000e+01
Merit	2.591430e-01

Figure 12: Merit Figure Table