Circuit Theory and Electronics Fundamentals

Instituto Superior Técnico, University of Lisbon

Laboratory 3

MeAer

Dinis Salgado, 90560

Bruno Santos, 98460

Laura Cebola, 98464

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Contents

1 Introduction

The objective of this laboratory assignment is to create a AC/DC converter circuit (230V to 12V) using the knowledge we have acquired in the theoretical classes (lecture 14). We were free to choose the architecture of the Envelope Detector and Voltage regulator circuits. The primal objective was to create an AC/DC circuit with the highest possible merit figure.

This Merit Figure is given by:

$$M = \frac{1}{cost \times (ripple(V0) + average(V0 - 12) + (10^{-6}))} \tag{1}$$

cost = cost of resistors + cost of capacitors + cost of diodes
cost of resistors = 1 monetary unit (MU) per kOhm
cost of capacitors = 1 MU/μF
cost of diodes = 0.1 MU per diode

The Circuit that we have created and we are going to analyse in this report, is composed by 23 diodes, one independent voltage source V_S, one dependent voltage source V_2, a dependent current source I_1, two resistors, R, and a capacitor C. The circuit can be seen in Figure 1.

In Section 3, a theoretical analysis of the circuit is presented. In Section 2, the circuit is analysed by simulation, and the results are compared to the theoretical results obtained in Section 3.The conclusions of this study are outlined in Section 6.

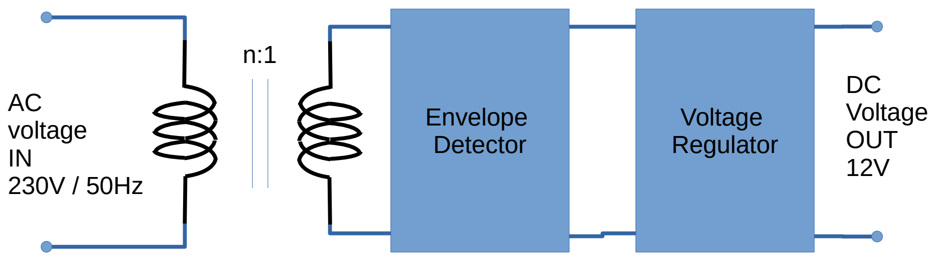

Figure 1: AC/DC Converter

2 Simulation Analysis

2.1 AC/DC Converter

The objective of this laboratory was to build an AC/DC converter. With this objective in mind, we have implemented the circuit that is represented below (Figure 2).
This circuit is constituted by two components, an envelope detector and a voltage regulator, that we are going to analyse in the next subsections.

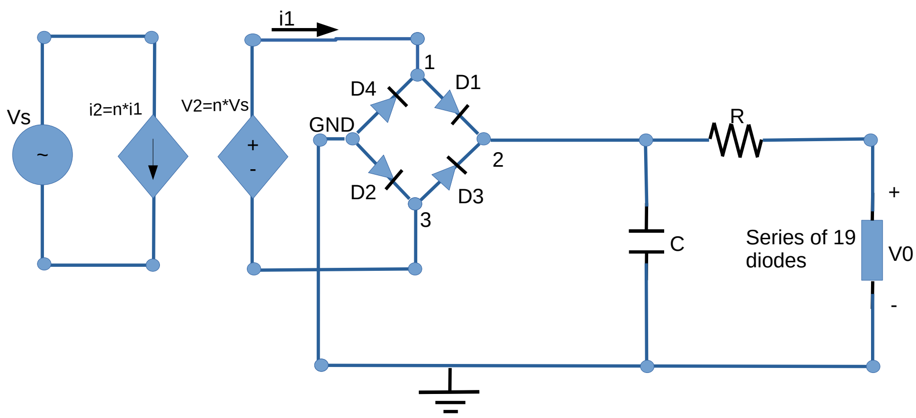

Figure 2: AC/DC Converter developed

2.2 Ideal Transformer

The ideal transformer was introduced in the circuit with two dependent sources, using the relations learned in the theoretical classes, with a n value, that will be balanced to obtain a voltage average of 12V.

2.3 Envelope detector

The purpose of the envelope detector is to convert the AC in a voltage that looks very similar to a DC, with little ripple oscillations.
This result was obtained using a fullwave rectifier and a capacitor. In the graphic below (Figure 3), it is shown the output at the terminals of this module.

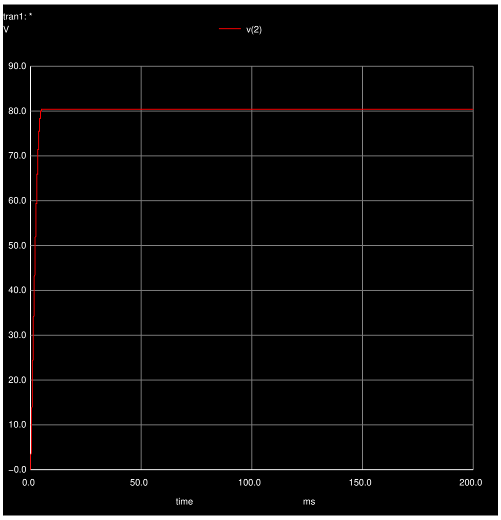

Figure 3: Envelope detector output

2.4 Voltage Regulator

This module purpose was to attenuate the ripple at the output of the detector envelope in order to improve the parameters. With the implementation of a resistor and 19 diodes in parallel we obtained the following response:

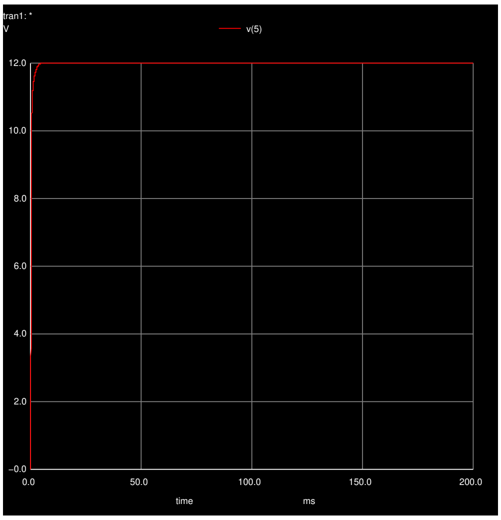

Figure 4: Voltage regulator output

We can verify and measure the values of the average voltage and of the ripple. This values will be presented in Table 1:

Name	**Value [V]**
vmax-vmin	1.800000e-04
vmax	1.200008e+01
vmin	1.199990e+01
vavg	1.200000e+01

Table 1: Values of average, maximum and minimum voltage and the ripple value

Finally, we have presented, graphically, $V0-12$ between 50ms and 100 ms in order to verify the behaviour (Fig 5). Also, we reduced the scale to perceive the slight variation in tension.

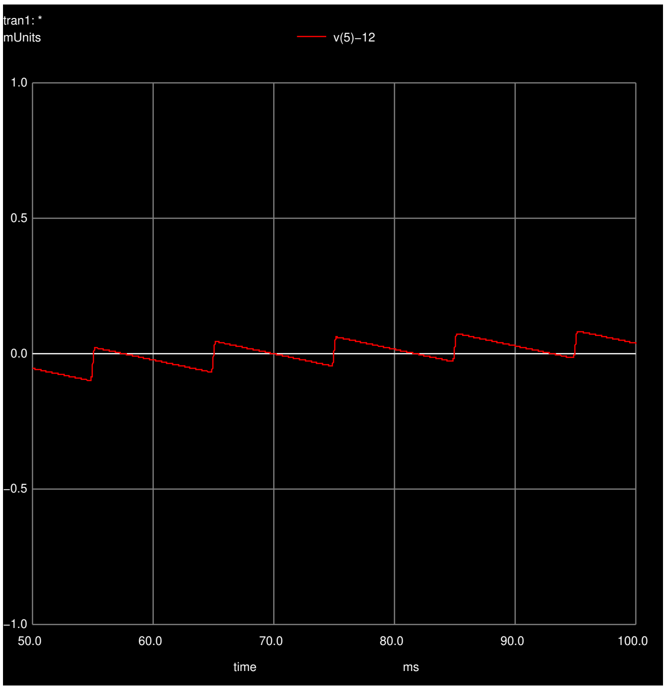

Figure 5: Ripple output (vO-12)

3 Theoretical Analysis

In this section, we used a suitable theoretical model that is able to predict the output of the Envelope Detector and Voltage Regulator circuits.

3.1 Computation of the fullwave rectifier

To compute the fullwave rectifier we used the ideal diode model+v0n approximation. Thus, the function at the output of the fullwave rectifier is defined by branches with the following expressions:

$$\begin{cases} vS > 1.4 & => vOfr = vS - 0.7 \\ vS < -1.4 & => vOfr = -vS - 0.7 \\ -1.4 < vS < 1.4 & => vOfr = 0 \end{cases}$$

The fullwave rectifier responses were the expected ones and are presented in the next figure (Fig 6):

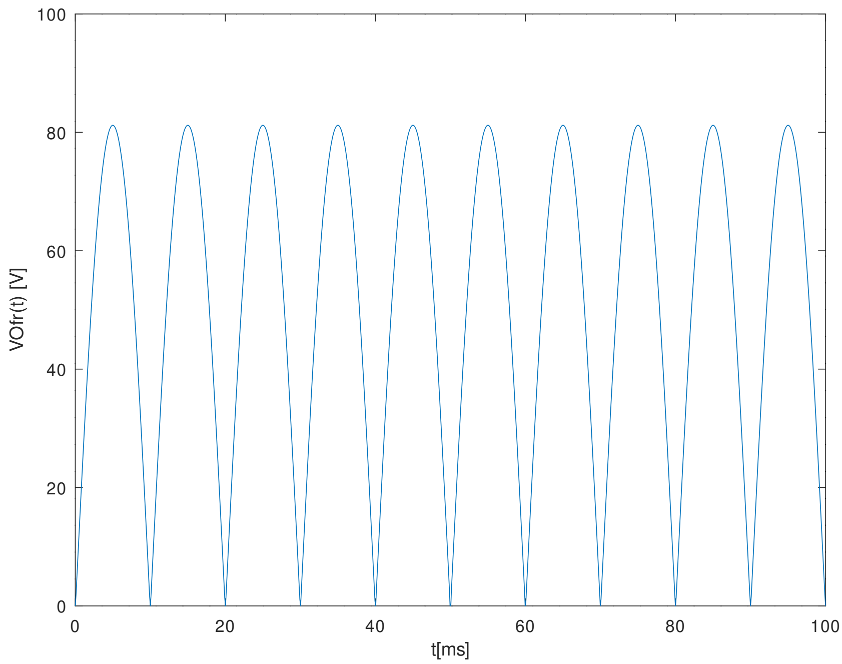

Figure 6: Fullwave rectifier output

3.2 Computation of the envelope detector

The next stage was to compute the envelope detector's response. This is, the result of having the capacitor, that does not allow the voltage to come down in the same way when it is discharging, what allows us to obtain a more constant voltage value with less oscillations. In this way, we used the next approximations, that we have learned in the theoretical classes:

$$\begin{cases} t < tOFF => vED = vOfr \\ tOFF < t < tON => vED = vOnexp \\ t > tON => vED = vOfr \end{cases}$$

With the t_{OFF} period defined by:

$$tOFF = tOFF + 1/(2 * f); \tag{2}$$

And with vOn_{exp}:

$$vOnexp = abs((A - 0.7) * sin(w * t_{OFF}) * exp(-(t - t_{OFF})/R/C)); \tag{3}$$

The result obtained was plotted and presented in the graphic below:

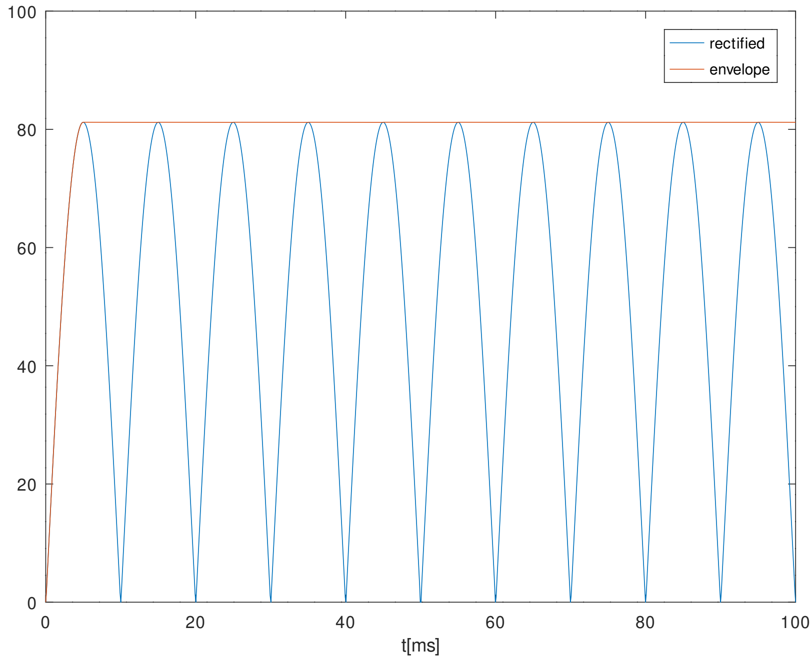

Figure 7: Envelope detector output

With this data, we were also able to calculate the ripple in the output of the envelope detector, using the max. and min. functions. The values are presented in the next table:

Name	**Value [V]**
vmax-vmin	1.800000e-04
vmax	1.200008e+01
vmin	1.199990e+01
vavg	1.200000e+01

Table 2: Values of average, maximum and minimum voltage and the ripple value

3.3 Computation of the voltage regulator

To determine the resistance value in each diode, we proceeded to do a simulation using the Ngspice tool. In this simulation we placed our voltage regulator, which contains 19 diodes and a resistance, with a DC voltage of 80,443 [V] and an AC voltage source with the arbitrary value of 10V.
From this point, we obtained the values of v_i and i_i with the approximation of $n * r_d = v_i/i_i$, then we calculated the resistance value for each diode, which was 1,229/19=0,06468 kOhm. With the previous value we calculated the ripple value at the regulator output through its gain:

$$ripple_{VR} = \frac{ripple_{ED} \times 19 \times rd}{(R + 19 \times rd)} \tag{4}$$

The ripple value corresponds to:

Name	Value [V]
Ripple	5.5747e-05

Table 3: Theoretical ripple value

The output plot of our converter, that is, after the envelope detector and the voltage regulator is as follows:

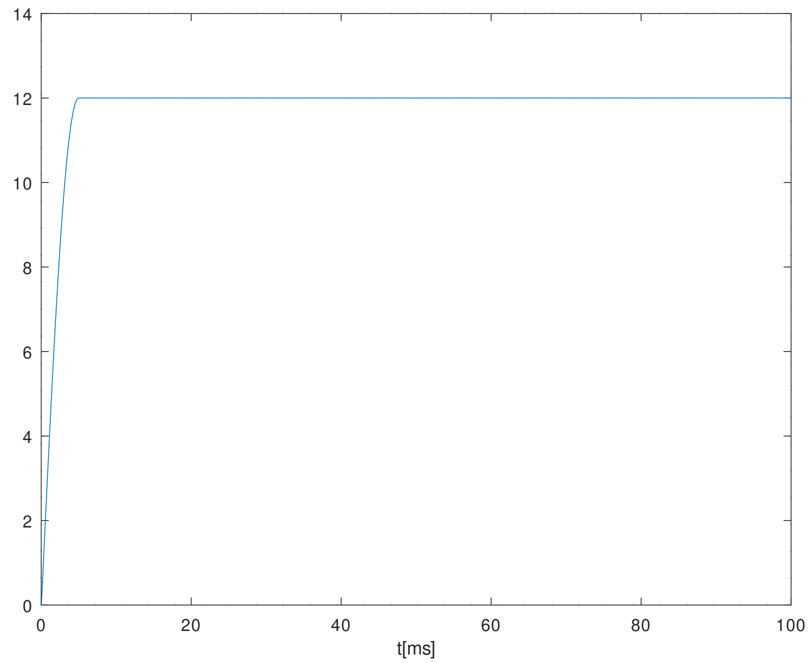

Figure 8: Final representation of the output voltage

4 Side by side analysis

In this section we are going to analyse and compare the plots and results generated with the Ngspice simulation, and with the Octave tool (Theoretical analysis).

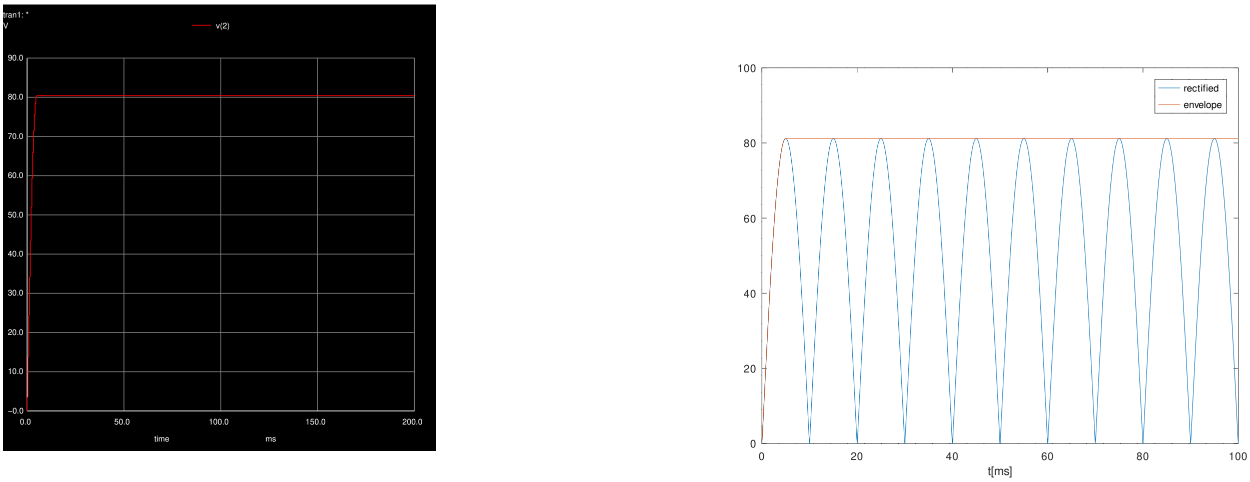

Figure 9: Envelope detector plots from Ngspice (left) and from Octave (right).

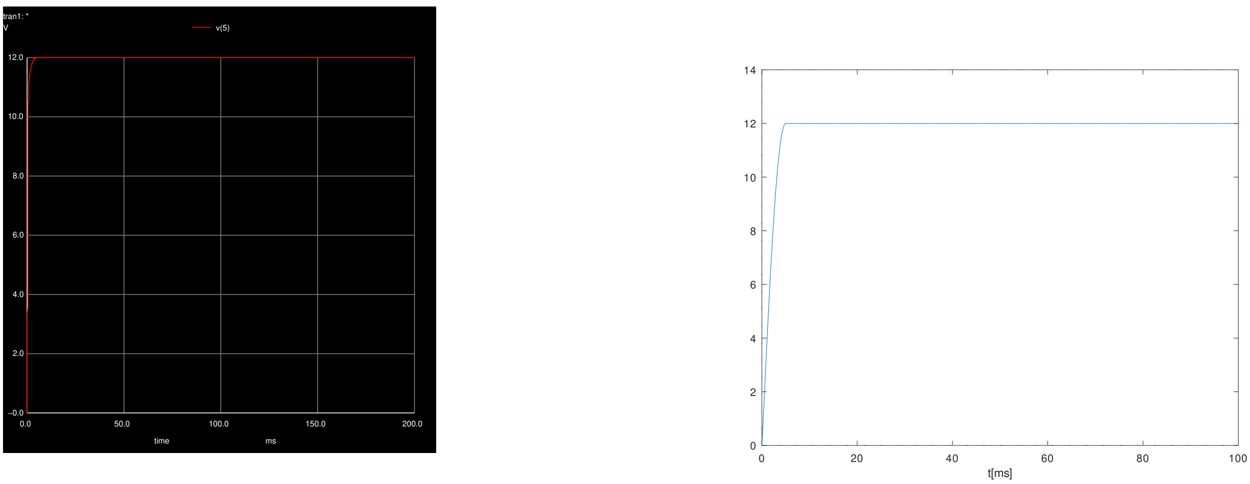

Figure 10: Voltage Regulator plots from Ngspice (left) and from Octave (right).

Name	Value [V]
Ripple	5.5747e-05

Table 4: Theoretical ripple value

Name	Value [V]
vmax-vmin	1.800000e-04
vmax	1.200008e+01
vmin	1.199990e+01
vavg	1.200000e+01

Table 5: Simulation ripple value

As we can observe, very similar results are represented in the plots, with little differences between them in the order of 10^{-4}. This differences are perceptible when we evaluate the theoretical and the simulated ripple. In the theoretical analysis we used several approximations that consider a better diode performance than the one that is simulated, so the theoretical ripple value is going to be inferior to the one obtained by the simulation.

5 Merit Figure

The principal objective of this work is to build a circuit with the highest merit figure as possible. For this Calculations we used the next expression:

$$M = \frac{1}{cost \times (ripple(V0) + average(V0 - 12) + (10^{-6}))} \tag{5}$$

Name	Value [MU]
Diodes	2.3
Resistance	170
Capacitor	305

Table 6: Cost value

Name	Merit
Msimulation	11.575
Mtheoretical	36.92

Table 7: Theoretical and simulation merit

cost = cost of resistors + cost of capacitors + cost of diodes
cost of resistors = 1 monetary unit (MU) per kOhm
cost of capacitors = 1 MU/μF
cost of diodes = 0.1 MU per diode

6 Conclusion

In this laboratory assignment, the objective was to implement an AC/DC (230/12) [V] with the highest Merit Figure as possible (this merit figure depends on the price of the components, and on the average ripple value), using the Octave Math tool and by running a simulation using the Ngspice tool.
In this laboratory we did not obtain the same values in the two analysis. This was due to the fact that the theoretical analysis makes a large number of simplifying approximations when analysing the diode model, that has a more ideal behaviour than the one that is used on the simulation, because of that in the case of the theoretical analysis the ripple was smaller and merit value was bigger than the one computed in the simulation.