TÉCNICO LISBOA

Lab 3: AC/DC Converter

Circuit Theory and Electronics Fundamentals
Master's programme in Engineering Physics, Técnico, University of Lisbon

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1 Introduction

The main objective of this laboratory assignment is to design an AC/DC converter. This circuit should be able to convert 230 V of alternating current at a frequency of 50 Hz (standard domestic electricity) to 12 V of direct current. To this purpose, three types of components will be employed: resistors, capacitors and diodes. The secondary goal is to achieve the best performance at the lowest cost. This is quantified by maximizing the following function:

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

$$cost = cost\ of\ resistors + cost\ of\ capacitors + cost\ of\ diodes$$
$$cost\ of\ resistors = 1MU/k\Omega$$
$$cost\ of\ capacitors = 1MU/\mu F$$
$$cost\ of\ diodes = 0.1MU/diode$$

In Section 2, the converter and its behaviour are presented. This is followed by a theoretical analysis of the circuit, in Section 3. Both are compared in the final section, Section 4. Here, M is also presented, allowing for some considerations to be made about the circuit designed. The simulation was run by using **Ngspice** and the theoretical calculations were performed with **Octave**.

2 Simulation Analysis

The basic template for a converter circuit is as follows:

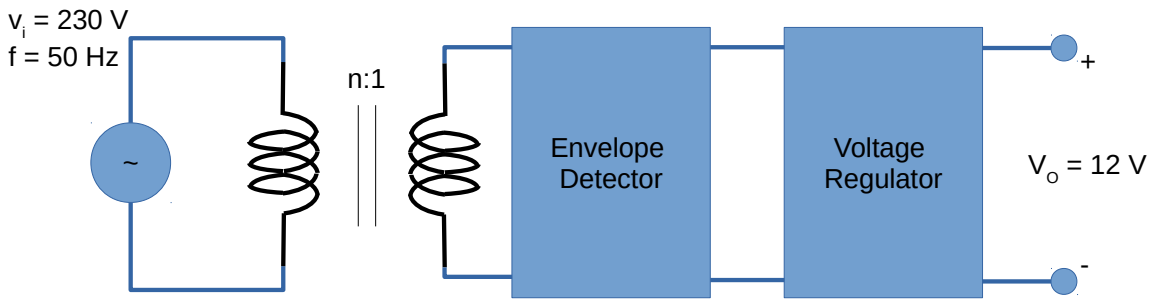
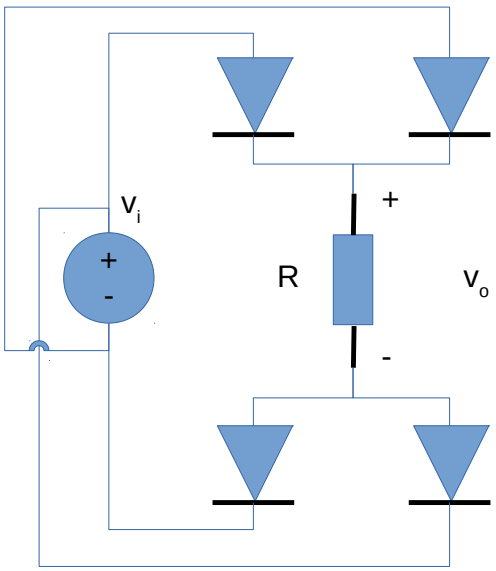


Figure 1: Template

2.1 Envelope Detector

An Envelope Detector is comprised of a rectifier and a capacitor.

The rectifier can be either a half-wave rectifier or a full-wave rectifier. A half-wave rectifier only allows for the transfer of positive voltage, therefore resulting in null voltage if the input voltage is negative. The full-wave rectifier allows for the transfer of the absolute value of the voltage. For our circuit, we decided to employ a full-wave rectifier, so as to have as small a gap as possible between peaks in the voltage, and therefore make it easier to even out later in the circuit.



$$v_{out} = |v_{in}|$$

Figure 2: Full-wave rectifier

We now have the module of the initial signal. In order to start bridging the oscillations, a capacitor is placed next to the rectifier, which discharges as the voltage drops, therefore bridging some of the gap.

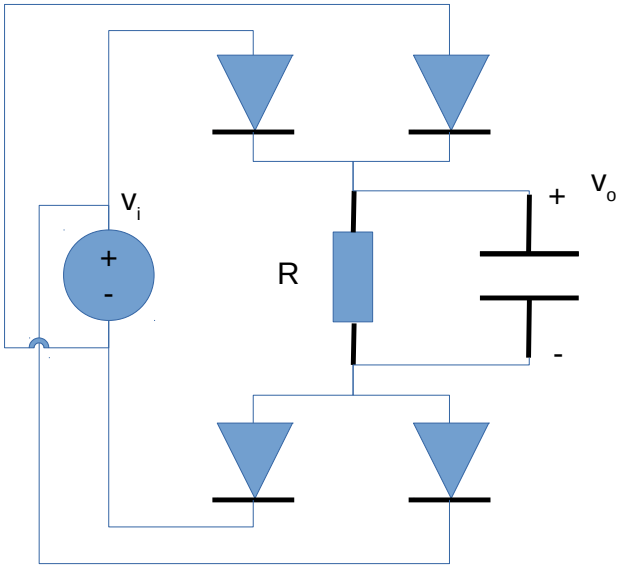


Figure 3: Envelope Detector

2.2 Voltage Regulator

The purpose of the Voltage Regulador is, as the name suggests, to limit the voltage output. One such circuit is as follows:

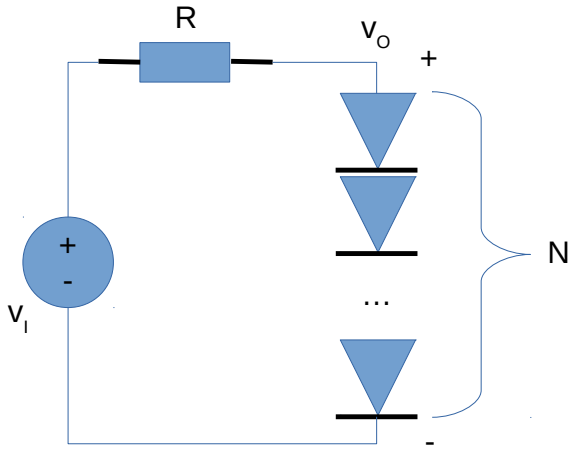


Figure 4: Voltage Regulator

It is known that:

$$v_O \leq NV_{ON} \tag{2}$$

By performing incremental analysis (that is, saying that each diode is equivalent to a resistor r_d):

$$v_o = \frac{N\ r_d}{N\ r_d + R} v_i \tag{3}$$

This implies that, if R is much greater than $N\ r_d$, then the amplitude of v_o (AC signal) is almost null, which is our goal. However, this must be balanced with the cost, as resistors are expensive (diodes, on the other hand, are not, so as many as needed may be added to cap v_o at around 12V).

2.3 Final result

Combining the envelope detector and the voltage regulator, our circuit is as follows:

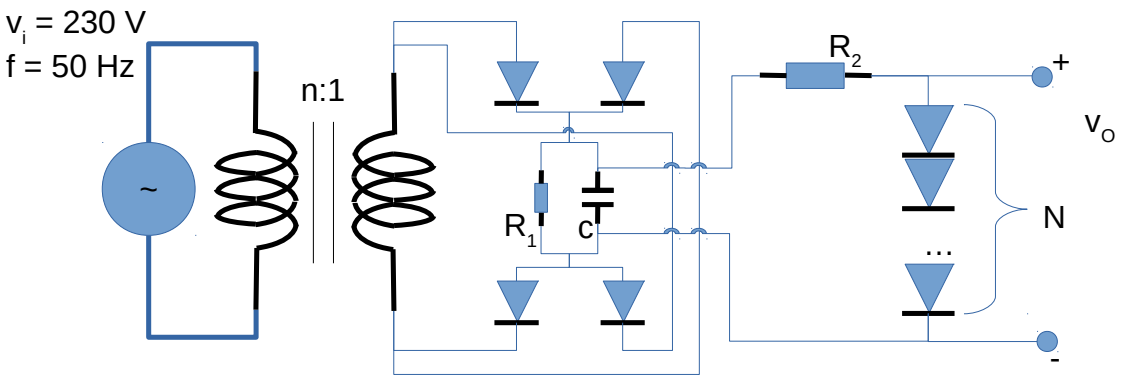


Figure 5: Our template

By a lengthy process of trial and error, attempting to maximize the merit figure gave us the following parameters:

Parameter	Value
R1($k\Omega$)	10.82
R2($k\Omega$)	1.12
C(uF)	40.0
N	18

Table 1: Parameters

Following this are shown the time evolution outputs for the Envelope Detector and Voltage Regulator Circuit and also the ripple in v_o.

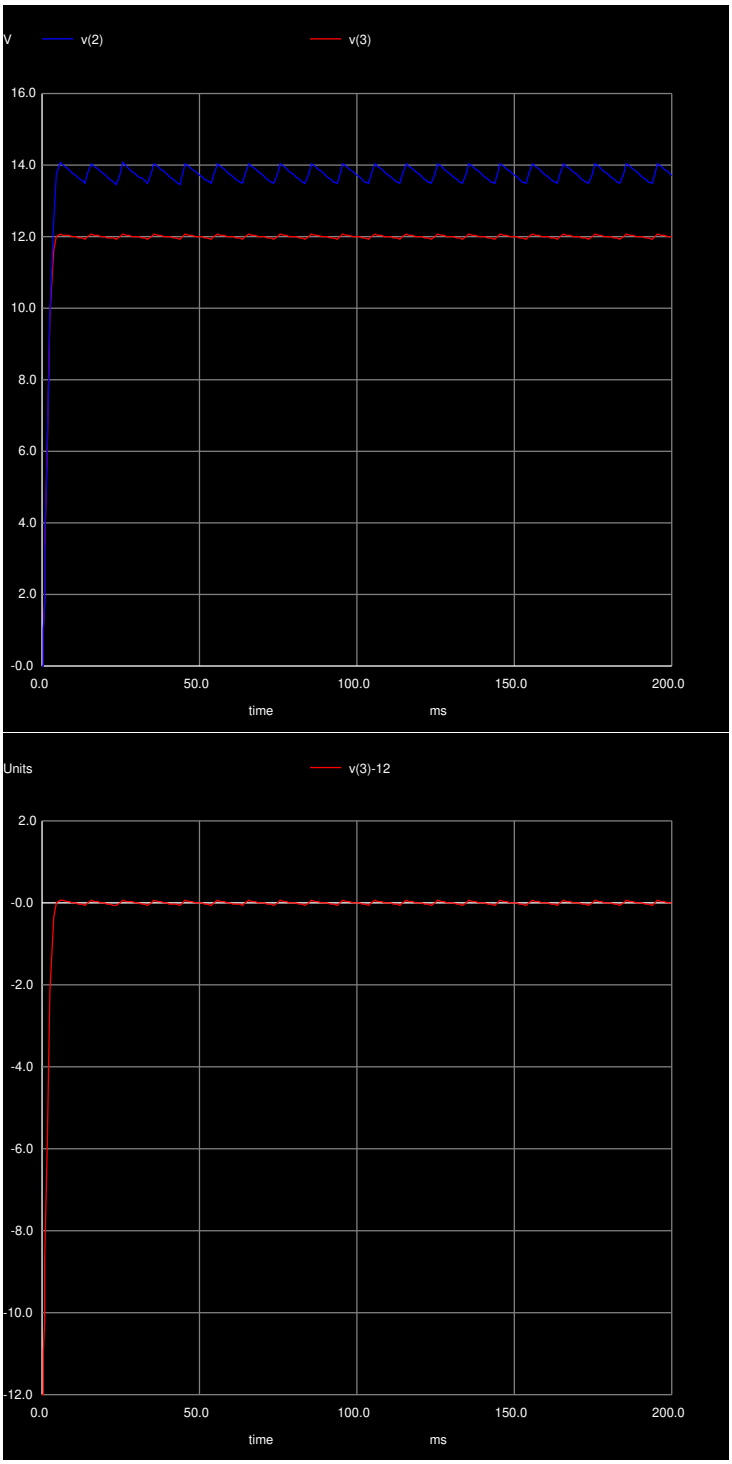


Figure 6: Simulation results: First graph - Envelope Detector (blue) and Voltage Regulator (red) output voltages; Second graph - Voltage Regulator output voltage minus 12V

3 Theoretical Analysis

As already mentioned, to perform the theoretical analysis of the circuit in figure 5 **Octave** was used. With this tool, we simulated the sine wave of the circuit after going through the transformer. Then that wave goes through the full-wave rectifier. As already mentioned, this rectifier (using the ideal diode model) transforms the signal to its absolute value. Next, using the capacitor, the signal starts to really look like a DC voltage. In figure 7, it is possible to observe the output voltage of the Envelope Detector. After an initial time, the voltage oscillates near 15V.

After the envelope detector, the signal goes through the Voltage Regulator. To study this part of the circuit, we used incremental analysis, where the diodes can be considered resistors r_d.

$$r_d = \frac{\eta V_T}{I_S e^{\frac{V_D}{\eta V_T}}} \tag{4}$$

The value of $V_D = V_{ON}$ was estimated to be the value of the average obtained in **Ngspice** divided by N. We considered $V_T = 25\ mV$, $\eta = 1$ and $I_S = 1.0 \times 10^{-14}$ (used by **Ngspice**).

With equation 3, obtained with voltage divider, we get the AC component of the final signal. The total signal will be the sum of the AC component with the DC component, NV_{ON}.

Finally, we obtained the output voltage represented in figure 7 for the Voltage Regulator. After the initial period, this voltage is almost constant at 12V, as desired, which can be easily observed in figure 8. It is apparent that this voltage oscillates significantly less than the output voltage of the Envelope Detector.

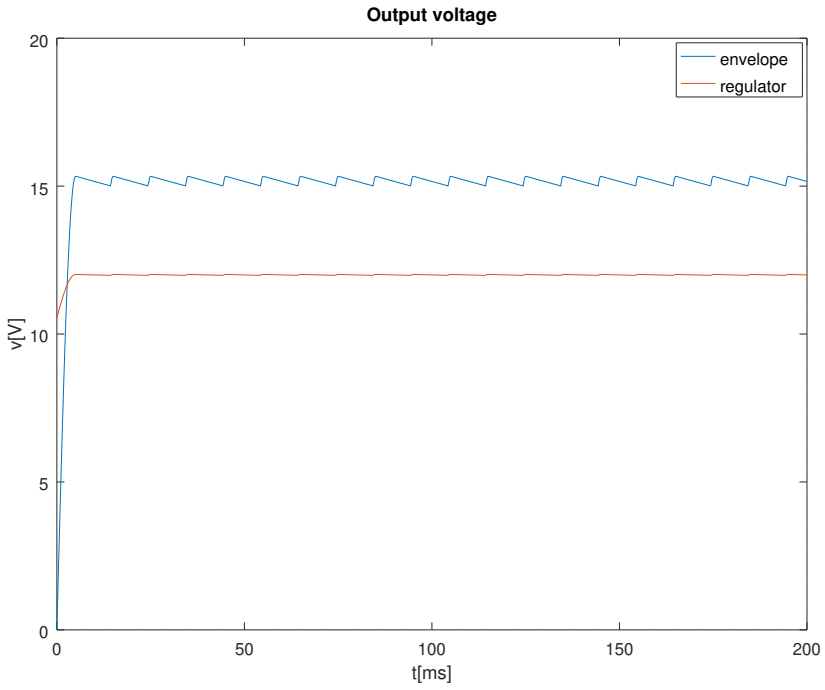


Figure 7: Output voltages of the Envelope Detector and of the Voltage Regulator

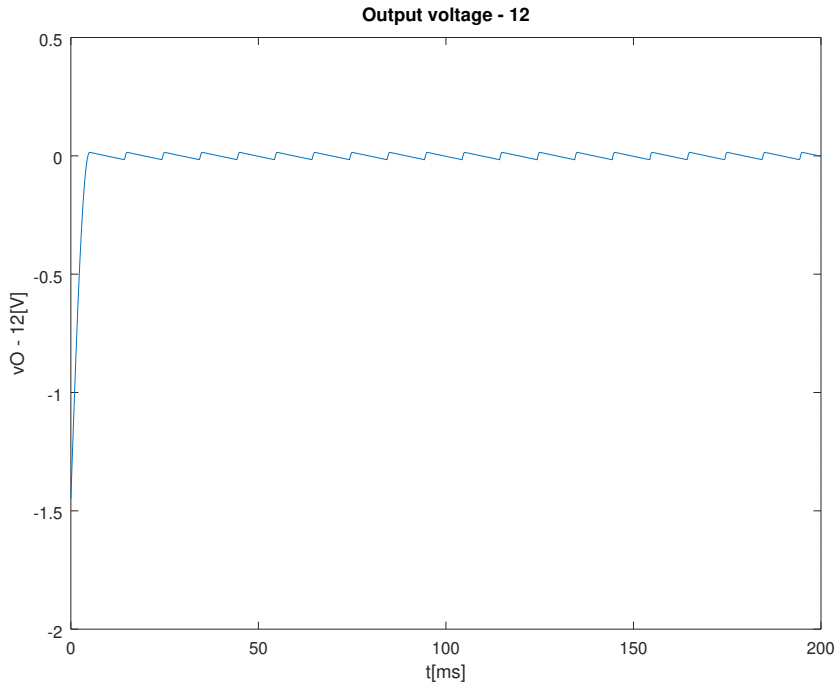


Figure 8: Output voltage of the Voltage Regulator minus 12V

4 Conclusion

This laboratory assignment had as the main objective the construction and analysis of an AC/DC converter. The chosen design is present in Figure 5. The goal was to design a circuit capable of converting 230 V of AC with frequency of 50 Hz to 12 V of DC. The analysis of the circuit was achieved by performing a simulation, using **Ngspice**, and a theoretical analysis, using **Octave**. By analysing the results obtained, we conclude that we were able to achieve a good result, the output voltage is very near from 12V and has a small ripple.

The merit figure of our circuit is: 0.1526 .

Some deviations between the simulation and theoretical results were expected, due to the different model used by **Ngspice** for diodes. In the theoretical analysis, we used very simple models. On the other hand, **Ngspice** uses a model of the diode with 15 parameters. Comparing graphs 6, 7 and 8 allows us to conclude that the output voltages have a similar behaviour. However, we can see that, in the simulation, the Envelope Detector output voltage oscillates around 14V while in the theoretical analysis it oscillates around 15V.

Average	11.99949
Ripple	0.12144000000000155

Table 2: Average and ripple for the output voltage of the Voltage Regulator for the simulation

Average	11.999490
Ripple	0.031184

Table 3: Average and ripple for the theoretical output voltage of the Voltage Regulator

As it can be observed in the tables, the same output average was obtained, and had to be obtained, since the diode's V_{ON} was determined from the **Ngspice** voltage output average.

Some deviations were obtained in the ripple. As it was possible to observe in the graphs, the theoretical ripple is smaller than the one obtained in the simulation. Both the average and the ripple were calculated excluding an initial time interval.

All in all, the objetives were met. With more time and a lenghtier study, better results, especially in terms of reducing the ripple, could be obtained, and other solutions implemented.