Circuit Theory and Electronics Fundamentals 2020/2021

Integrated Masters in Aerospace Engineering, Técnico, University of Lisbon

Third Laboratory Report

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1 Introduction

The objective of this laboratory assignment is to study and implement an AC/DC converter circuit while, at the same time, trying to maximize the figure of merit M. The AC/DC converter circuit is composed of two circuits: an Envelope Detector circuit, an electronic circuit that takes a (relatively) high-frequency amplitude modulated signal as input and provides an output, which is the demodulated envelope of the original signal, and a Voltage Regulator circuit, a system designed to automatically maintain a constant voltage. The circuit can be seen in Figure 1.

In Section 2, a theoretical introduction is made in order to contextualize all the main principles that sustain our analysis of the circuit. This circuit is carefully analysed in Section 3, where the results are obtained in GNU Octave. Also, in Section 4, the circuit is analysed by simulation through the use of NGSpice to simulate the electric circuit behaviour. The results of the simulation of Section 4 are then compared to the theoretical results obtained in Section 3 and the comparative results are expressed in Section 5. The conclusions of this study are outlined in the final part of the report, in Section 6.

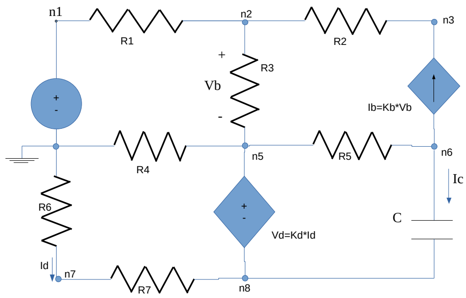

Figure 1: Third laboratory circuit.

2 Theoretical Introduction

3 Theoretical Analysis

In this section, we can find the results of an AC-DC converter build according to theoretical principles in order to be the subject of a theoretical analysis. The numeric results or graphics are presented alongside the formulas and methods used to claculate them. All of the results were obtained usig GNU octave and the section is organized in four different subsections, divding the converter into two circuits - the envelope detector circuit in Subsection 3.1 and the voltage regulator circuit in Subsection 3.2 - and analysing the final values of the ripple voltage - in Subsection 3.3 - and the output DC level - in Subsection 3.4.

3.1 Envelope Detector Circuit

We start to define some of the parameters needed in the composition of a envelope detector circuit, suchs as the resistance of resistor R and the capacitance of the capacitor C. We also present the voltage source v_S characteristic values, such as the frequency f (and the period T, as the inverse frequency value) and the amplitude A.

$$\begin{cases} f = 50Hz \\ A = 14V \\ R = 1000\Omega \\ C = 100\mu F \end{cases}$$

$$\begin{cases} T = \frac{1}{f} = 1/50s \\ \omega = 2\pi f = 100\pi rad/s \end{cases}$$

The voltage source v_S produces a sinusoidal wave and is defined by the following expression: $v_S = Acos(\omega t)$.

The envelope detector circuit includes a full-wave bridge rectifier, whose voltage output $v0_{rect}$ corresponds to the absolute value of the voltage source v_S.

$$v0_{rect} = \begin{cases} v_S, & v_S \geq 0 \\ -v_S, & v_S < 0 \end{cases}$$

Finally, the envelope detector circuit voltage v_0 is the highest between $v0_{rect}$, the full-wave bridge rectifier voltage, and the voltage $v0_{exp}$ induced when the capacitor C discharges through the resistor R and described by the following equation: $vO_{exp} = Acos(\omega t_{OFF})e^{(\frac{-(tON-tOFF)}{RC})}$.

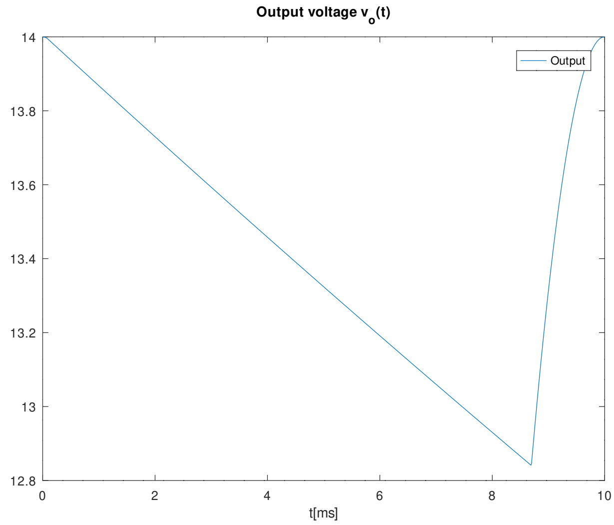

Figure 2: The final envelope detector circuit voltage v_0 during a half-period interval.

where t is expressed in miliseconds (ms) along the x-axis
and v_0, the envelope output voltage, is expressed in Volts (V) along the y-axis.

3.2 Voltage Regulator Circuit

The voltage regulator attenuates oscillations in the input signal without frequency dependence and takes advantage of the non-linear characteristic of the N diodes included in the positive voltage limiter.

We start to define some of the parameters needed in the composition of a voltage regulator circuit, suchs as the resistor R_2 value and the number of diodes n of the voltage limiter. We also present the diode's characteristic values, such as the emission coefficient η, the reverse saturation current I_S, the thermical voltage v_T and the diode voltage v_D.

$$\begin{cases} N = 17 \\ R_2 = 10k\Omega = 10000\Omega \\ \eta = 1 \\ v_t = 0.025V \\ v_d = 0.706V \\ I_s = 1 \times 10^(-14) \end{cases}$$

The voltage analysis of the regulator applies the incremental analysis method, separating the DC and incremental components.

The diode incremental resistance is calculated using the following expression: $r_d = \frac{\eta v_t}{I_s e^(\frac{v_d}{\eta v_t}}$.

Applying the voltage divider rule, the AC increment v_{out} is defined using the following relation: $vout = \frac{Nr_d}{Nrd+R2} vO$.

It is easy to understand that a large value of the resistor R_2 will maximize the denominator and make it significantly bigger than the numerator ($Nrd + R2 >> Nr_d$), which makes the whole quotient tend to zero ($\frac{Nr_d}{Nrd+R2} \longrightarrow 0$). While we minimize the AC increment, we are at the same time increasing the precision of the DC voltage, as pretended when building an AC-DC converter.

On the other hand, the DC voltage V_{OUT} is obtained multypling the diode voltage v_d by the number of diodes N used in the voltage regulator circuit: $V_{OUT} = Nv_d$.

The final voltage of the regulator circuit v_{OUT} is obtained adding the results of the incremental analysis and the DC analysis: $v_{OUT} = v_{out} + V_{OUT}$.

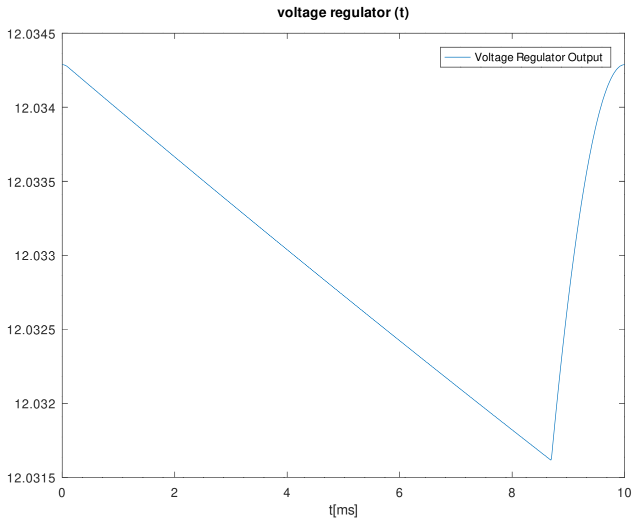

Figure 3: The final voltage v_{OUT} of the voltage regulator circuit during a half-period interval.

where t is expressed in miliseconds (ms) along the x-axis
and v_{OUT}, the voltage of the regulator, is expressed in Volts (V) along the y-axis.

3.3 Voltage Ripple

The voltage ripple can be improved using a full-wave rectifier circuit in the envelope detector circuit.

The value of the voltage ripple v_{ripple} can be calculated relating the maximum and the minimum values of the final voltage of the regulator circuit v_{OUT}, using the following expression: $v_{ripple} = max(v_{OUT}) - min(v_{OUT})$.

The Output Voltage RIPPLE is	0.00267197 V

3.4 The Output DC Level

The t_{ON} is calculated using the Newton-Raphson iterative method, starting with a function obtained through the following equation: $Acos(\omega t_{ON}) = Acos(\omega t_{OFF})e^{(\frac{-(t_{ON}-t_{OFF})}{RC}})$.

The DC level output average is obtained integrating the sinusoidal and exponential functions during a half-period interval. The calculations are shown below.

$t \in [0, t_{OFF})]$
$\int_0^{t_{OFF}} = \frac{Nr_d}{Nr_d+R_2}\frac{A}{\omega}sin(\omega t_{OFF}) + Nv_d t_{OFF}$

$t \in [t_{OFF}, t_{ON}]$
$\int_{t_{OFF}}^{t_{ON}} = \frac{Nr_d}{Nr_d+R_2}(-ARCcos(\omega t_{OFF})(e^{\frac{-(tON-tOFF)}{RC}} - 1)) + Nv_d(t_{ON} - t_{OFF})$

$t \in [t_{ON}, \frac{T}{2}]$
$\int_{t_{ON}}^{\frac{T}{2}} = \frac{Nr_d}{Nr_d+R_2}\frac{A}{\omega}(sin(\omega\frac{T}{2}) - sin(\omega t_{ON})) + Nv_d(\frac{T}{2} - t_{ON})$

$$\overline{V} = \frac{\int_0^{t_{OFF}} + \int_{t_{OFF}}^{t_{ON}} + \int_{t_{ON}}^{\frac{T}{2}}}{\frac{T}{2}}$$

The Output Voltage AVERAGE LEVEL is	12.0248 V

The Output DC Level accuracy can be evaluated through comparing the final voltage of the circuit v_{OUT} and the $12V$ constant function.

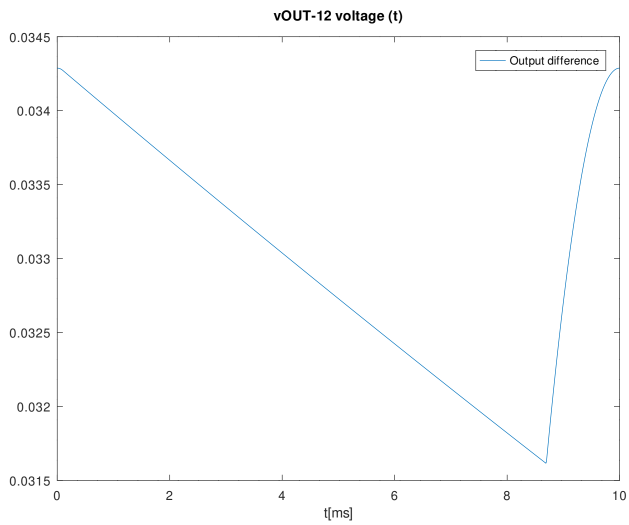

Figure 4: The voltage $(v_{OUT} - 12)$ during a half-period interval.

where t is expressed in seconds (s) along the x-axis
and $(v_{OUT} - 12)$, the output voltage difference, is expressed in Volts (V) along the y-axis.

4 Simulation Analysis

In this section, we can find the results of each topic required in the simulation analysis. The numeric results or graphics are presented alongside a short explanation of the interpretation of the problem. All of the results were obatined usig NGSpice and the section is divided in two different subsections.

In this part of the lab, we tried to build the circuit in such a way that it would be as similar as possible as the one used in the Octave theoretical part. The most important difference between both approaches is that in Ngspice we had to use more diodes in the regulator circuit than in Octave. This is because while in Octave we used the standard diode voltage $(0.7V)$, requiring 17 diodes, in Ngspice that wasn't possible because diodes have varying voltages. Given that, our Ngspice voltage regulator circuit is made of 23 diodes.

Another difference from the Octave model, is that the ideal diode model used in the envelope circuit is not possible to replicate in Ngspice. However, this does not affect the final results because the transformer conversion factor was updated to compensate the fact that there is going to be a voltage drop in the envelope circuit diodes.

4.1 Envelope Circuit Output

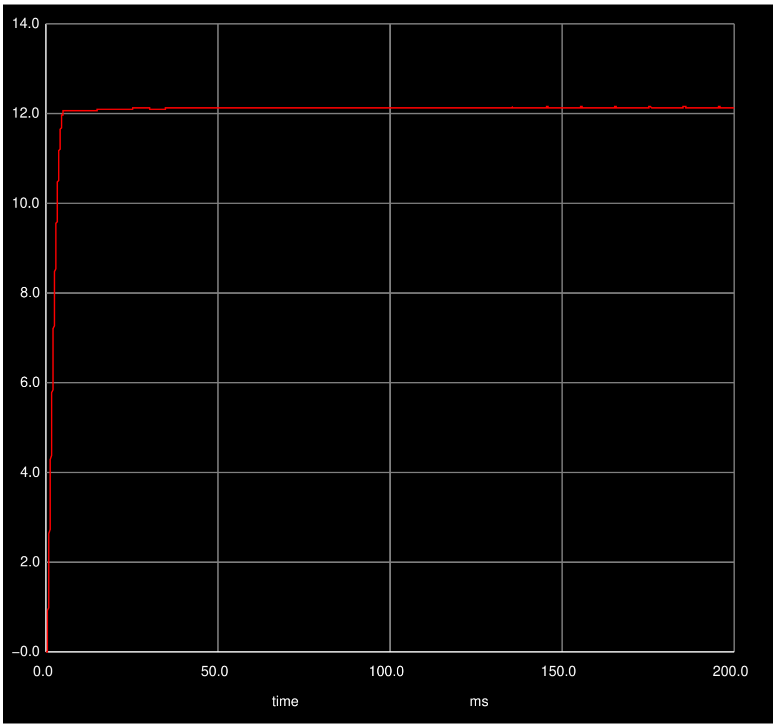

Figure 5: The final envelope detector circuit voltage v_0 during 10 periods

In the graphic above, it is possible to see that, even though it is not the final result of the whole converter, it is already very close to $12V$. It is important to note that, if we zoom in, there will be a certain level of ripple that may affect our desired result, given that the signal hasn't gone throught the voltage regulator yet. Still on this topic, a particularity of Ngspice is the rising line at the very beginning which clearly stands for some transient the software uses.

4.2 Circuit Output

In this part the total output of the circuit is analysed.

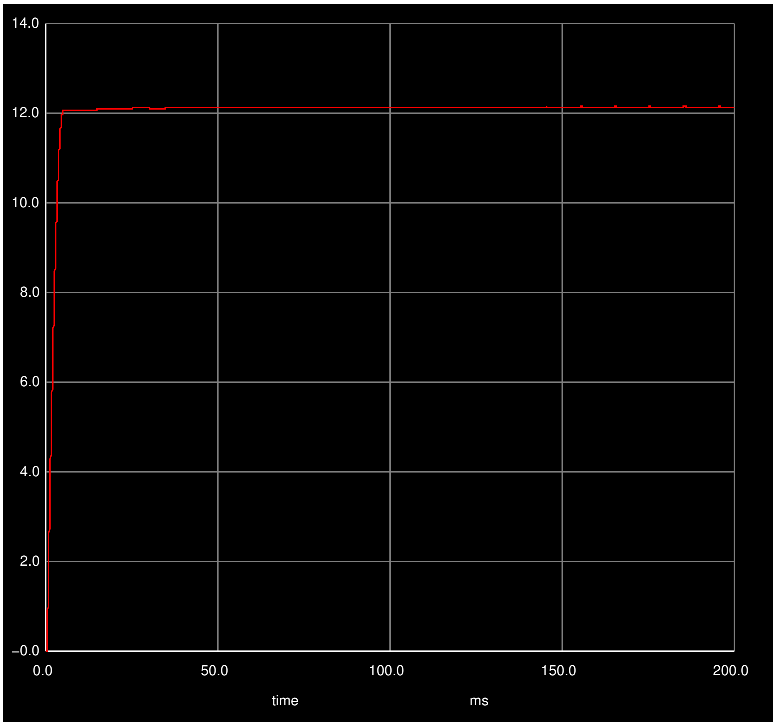

Figure 6: The final output voltage v_0 during 10 periods

In the graphic above, the output voltage is represented. Looking at it is enough to understand that the final voltage is very close to the desired $12V$, however the difference that remains will be discussed below.

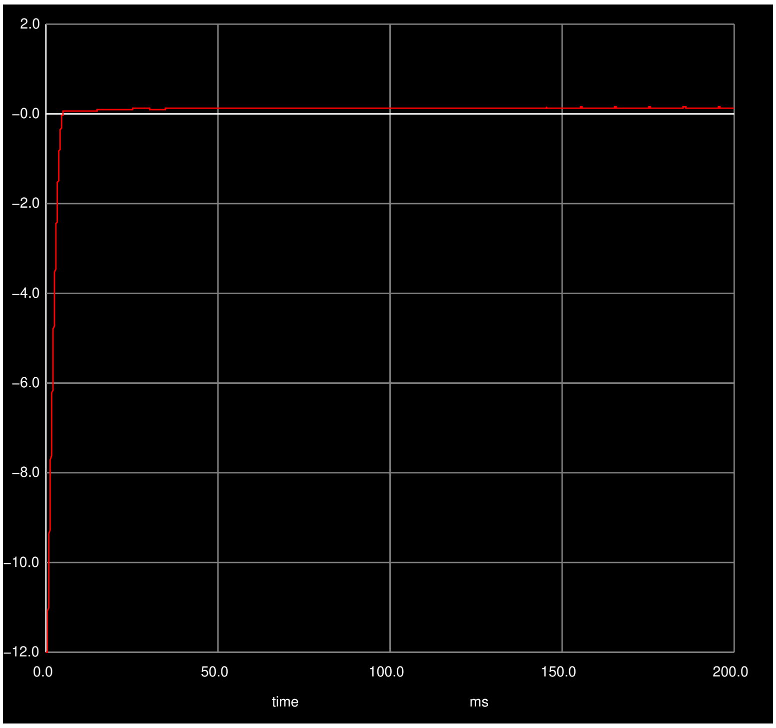

Figure 7: The final output voltage v_0 subtracted by 12 during 10 periods

The graphic above essentialy shows the ripple of the circuit, which is basically how much the output voltage deviates from $12V$ and, once again, the results are pretty satisfying, with the line being very close to zero for most of the 10 periods. Still, below we can find a table with more accurate ripple data at a numerical level, which will confirm the theory that the simulation was well-succeeded.

Data	Value
max	1.214333e+01
min	1.212654e+01
ripple	1.679523e-02
average	1.200008e+01

Table 1

From the table above, we can see that the average has a pretty good result being pratically $12V$. When it comes to the ripple, it also has a very good result, with an order of significance in the hundredths.

5 Relative Error and Graphic Analysis

5.1 Topic I

6 Conclusion

In this third laboratory assignment, all the major goals of the project were achieved. We concluded with success a further interaction with a new software (Ubuntu), with a simulation software (Ngspice), with a computational language program (GNU Octave) and with a text report editor (LaTeX). The analysis of the circuit was also finished with success through simulation and theoretical interpretation, which allowed a good comparative analysis between these two methods.