Instituto Superior Técnico, University of Lisbon

Integrated Master in Aerospace Engineering

Circuit Theory and Electronics Fundamentals

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Third Laboratory Report

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Contents

1 Introduction

The objective of this laboratory assignment is to simulate a AC/DC converter circuit, which output voltage must be ideally 12 Volts. This converter must have an envelope detector and a voltage regulator. We are free to choose the architecture of both circuits, however we must consider the cost of the components in the circuit, the ripple voltage and the voltage difference between the output voltage and 12 Volts.

After multiple simulations, we have decided to simulate the following circuit. The envelope detector is composed by a full rectifier brigde and a resistor R_1 in parallel with a capacitor C, while the voltage regulator has a resistor R_2 in series with 20 diodes. The values of the components are exhibited in the table below. We have also taken advantage of the fact that, in this assignment, the number of turns n of the transformer will not influence the merit of our work. Therefore, as you can see below, we used an unusual value for n.

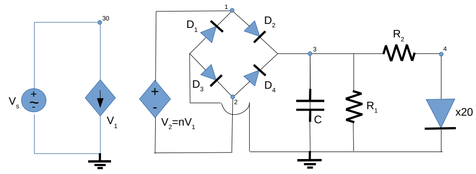

Figure 1: AC/DC converter circuit.

V_{in}	2.300000e+02 V
f	5.000000e+01 Hz
n	1.120349e+01
R_1	6.000000e+04 Ohm
R_2	6.000000e+04 Ohm
C	1.000000e-04 F

Table 1: Data

In Section 2, a theoretical analysis of the circuit, performed on Octave, is presented. In Section 3, the circuit is analysed by simulation, using NGSpice, and the results are compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 4.

2 Theoretical Analysis

In this section, the circuit shown in Figure 1 is analysed theoretically. We will begin by analyzing the Envelope Detector circuit and, after that, the Voltage regulator circuit, in order to predict their outputs.

The theoretical values will be obtained by applying Kirchhoff laws and the diode equations. Considering the circuit of Figure 1, it is composed by a Voltage source, a transformer, an envelope detector and a voltage regulator.

The amplitude and the frequency of the voltage source are equal to 230V and 50Hz, respectively. However, the transformer will convert this into a lower voltage, supllying the rest of the circuit with a voltage, Vs(t):

$$V_s(t) = A \cdot cos(wt) \tag{1}$$

, where

$$w = 2 \cdot \pi \cdot f \tag{2}$$

It is important to notice that $A = (\frac{230V}{n})$. The value of the constant n was already indicated on Section 1.

2.1 Envelope Detector

The envelope detector consists of a rectifier, composed by four diodes, a resistor, R1, and a capacitor, C.

The rectifier used on this AC/DC converter was a full-wave rectifier, more specifically, a bridge rectifier. Theoretically, this rectifier produce an output of $V_{rectifier} = |V_s(t)|$.

The capacitor reduces the magnitude of the voltage. This way, we need to determine when diodes are ON and OFF, where

$$tOFF = \frac{1}{w} \cdot atan(\frac{1}{w \cdot R1 \cdot C}) \tag{3}$$

So, for t<tOFF,

$$V_{envelope} = V_{rectifier} \tag{4}$$

but if t>tOFF,

$$V_{envelope} = A \cdot cos(w \cdot tOFF) \cdot exp(\frac{-(t - tOFF)}{R1 \cdot C}) \tag{5}$$

The ripple voltage is equal to $max(V_{envelope}) - min(V_{envelope})$.

Name	Value [V]
Ripple Envelope	3.353448e-02
Average Envelope	2.051255e+01

Table 2: Ripple and average envelope values

2.2 Voltage Regulator Circuit and Final Outputs

The voltage regulator circuit takes advantage of the fact the diodes are non-linear components to attenuate the oscilations in the input signal without frequency dependence. In our case, the voltage regulator is composed by 20 diodes connect in series and one resistance with the value of R2.

The DC voltage in the regulator is the minimum between the average envelope and the voltage in each diode terminals times the number of diodes connected in series. Using the equation:

$$r_d = \frac{\eta \cdot V_T}{I_s \cdot \exp(\frac{V_d}{\eta \cdot V_t})} \tag{6}$$

, to compute the resistance seen by each diode terminals and calculate the AC voltage seen in the regulator. This means that the output DC voltage will be the sum of the AC voltage previously mentioned and the DC voltage previously mentioned, giving us the following graphics:

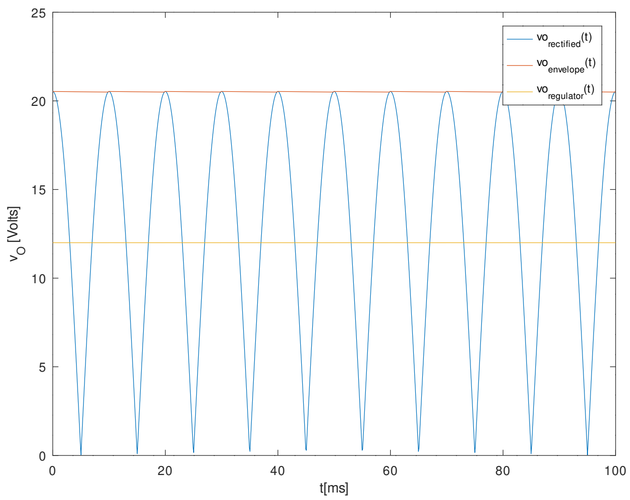

Figure 2: Rectifier output, Envelope Output, Voltage Regulator Output

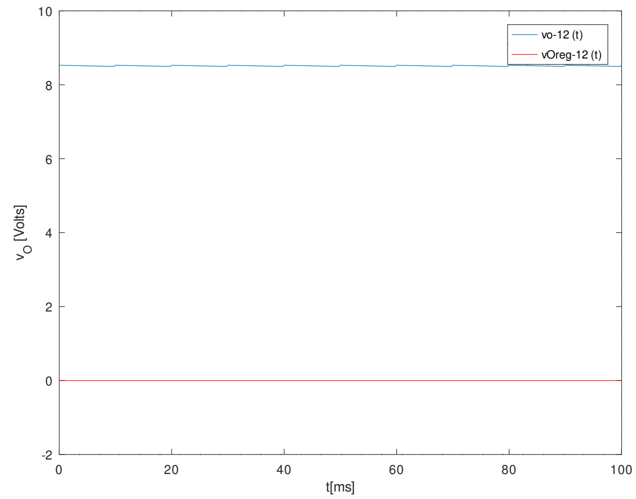

Figure 3: Output AC components + DC deviation

Furthermore, we also obtain:

Name	Value [V]
V_{max}	1.200051e+01
V_{min}	1.199949e+01
Average Voltage	1.200000e+01

Table 3: Average Regulator

Name	Value [V]
Ripple Voltage	1.022800e-03

Table 4: Ripple Voltage

Ideally, the output DC voltage will be a constant equal to 12 Volts. And by analysing the graph and comparing it to the simulation we can conclude that it was /was not achieved a acceptable result.

3 Simulation Analysis and Comparison with Theoretical Results

3.1 Transient Analysis

Figure 4 shows the simulated transient analysis results for input voltage of the secondary circuit, the envelope detector output voltage, V_3, the voltage regulator output voltage, V_4 and the average voltage difference, V_4-12 Volts.

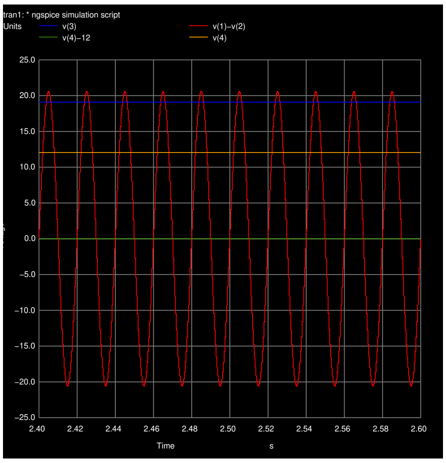

Figure 4: Transient input voltage of the secondary circuit and transient output voltage of both the envelope detector and voltage regulator and the average voltage difference.

By analysing the result of the simulation we notice that the output solution resulted in an aproximated sinusoidal fuction: in fact, because of the average voltage is not ideal, the curve has an upward sinusoidal motion and a downward motion described by a negative exponential. The input voltage is described by a sinusoidal fuction, as expected. As far as the result is concerned, the form of the theoretical solution match the one obtained by NGSpice. Note that, because of the scale, we can not see the wave form of the ripple voltage and voltage difference because they are very small, which means that we obtained a decent result for 2 of the 3 parameters that influence the merit.

Table 5 shows the measured results for the maximum, minimum and average output voltage of the circuit V_4. Notice that the values on the right were obtained by Octave, therefore they are the theoretical values, which we already mentioned previously but, to facilitate the comparison between the simulation and theoretical values, we mentioned them again.

Name	**Voltage[V]**	**Node**	**Voltage[V]**
maximum(v(4))	1.199937e+01	V_{max}	1.200051e+01
minimum(v(4))	1.199668e+01	V_{min}	1.199949e+01
mean(v(4))	1.199803e+01	Average Voltage	1.200000e+01

Table 5: Measured maximum, minimum and average output voltage of the circuit. The values on the right are the theoretical values for the same voltages in the circuit.

Compared to the theoretical analysis results, we notice that both simulation results are accurate, except for the last decimal places, as a consequence of the cientific notation and the number of significative algharisms used by each program to present the results. Despite that, we realise that the values with more significant algharisms match correctly the rounded values.

Table 6 shows the ripple voltage of the circuit and the average voltage difference between the output voltage and 12 Volts. Again, we show the theoretical values obtained for this step, to make it easier to compare between simulation and theoretical values.

Name	Voltage[V]
maximum(v(4))-minimum(v(4))	2.691280e-03
mean(v(4)-12)	-1.96862e-03

Name	Voltage[V]
Ripple Voltage	1.022800e-03

Table 6: Ripple voltage maxV_4 - minV_4 and the average voltage difference V_4 - 12. The values on the right are the theoretical values for the same voltages in the circuit.

Table 7 shows the total cost of the circuit and the figure of merit of the circuit. Note that we used the simulated voltage results to calculate the value of merit.

Formula	Merit
1/ (222.4* ((maximum(v(4))-minimum(v(4))) + mean(v(4)-12) + 1e-6))	6.213422e+00

Table 7: Figure of merit with a cost of 222.4 monetary units (MU).

By analising the figure of merit, we note that its value, considering the multiple results obtained for different values of the components and layots of the circuit, is reasonable. Nevertheless, we consider the result not satisfying, since we obtained a merit of around 900 when we eliminated resistor R_1 and added 15 more diodes to the series (reducing considerably the cost, the ripple and the average voltage difference). However, the AC/DC converter obtained would not be an efficient one, since it would have an enourmous stabilization time and no resistor connected in parallel with the capacitor.

4 Conclusion

In this laboratory assignment the objective of analysing an AC/DC converter, made of an envelope detector and a voltage regulator, has been achieved. The theoretical analysis was performed with the help of the Octave math tool and the circuit simulation using the Ngspice tool. For both analysis, we plotted the output voltages of both the envelope detector and voltage regulator and, in the case of the regulator, we also determine the maximum, minimum and average output voltage, so we could measure the voltage ripple and difference between the output and 12V, to calculate the figure of merit. The simulation results matched the theoretical results accurately - furthermore, we obtained a low stabilization time and a decent figure of merit, despite the cost being too high.