Circuit Theory and Electronics Fundamentals

Técnico, University of Lisbon

T3: AC/DC Converter Circuit

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1 Introduction

The objective of this laboratory assignment is to model an AC/DC converter circuit, that can be seen in Figure 1 and is comprised of a transformer, an envelope detector and a voltage regulator.

In Section 2, a theoretical analysis of the circuit is presented. In Section 3, the circuit is analysed by simulation. In Section 4, the results obtained in Section 3 are compared to the theoretical results obtained in Section 2. The conclusions of this study are outlined in Section 5.

2 Theoretical Analysis

Because our input voltage was $Vs = 230V$, and the expected output voltage was 12V, a transformer was used to convert Vs into a smaller value, given by the expression $Vr = Vs/n$, with $n = 10$. On its own, however, this step doesn't solve the whole problem, as the objective of this assignment is to make an AC/DC Converter Circuit. So, we still need to convert the transformed AC voltage into a DC voltage. To do this, the circuit shown in Figure 1 was used.

This circuit is composed by three main subcircuits.

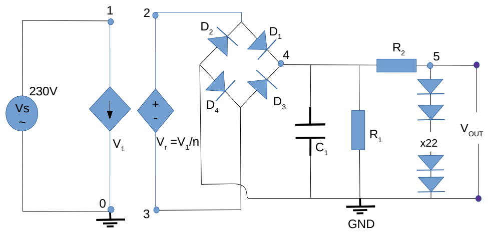

Figure 1: AC/DC converter circuit model.

The four diodes on the left make up the Full-wave Rectifier. This subcircuit is responsible for transforming the AC voltage into an equal amplitude but unidirectional voltage, as shown in green, in Figure 2. This can be computed by simply taking the absolute value of the transformed voltage vr.

After that, a capacitor is utilized to reduce the magnitude of the voltage, getting it even closer to a DC voltage, as shown in COLOR, in Figure 2. This can be computed by determining when the diodes are ON an OFF. Periodically, we get:

$$\begin{cases} vO = Vr \qquad ,t < t_{OFF} \\ vO = Vs \cdot cos(w \cdot t_{OFF}) \cdot exp(-\frac{t-t_{OFF}}{R_{eq} \cdot C}) \qquad ,t > t_{OFF}. \end{cases} \tag{1}$$

Finally, 22 diodes in series are used for the purpose of reducing the noise, making the plot even closer to DC, as shown in COLOR, in Figure 2. By calculating the vO average, one can see if the voltage drop at the diodes terminals is limited by the maximum voltage that those diodes can handle. This is the case when that average is greater than that maximum. After this, we are left with a voltage due to the DC component, so we still need to take into account the AC component. This can be computed by calculating rd (the resistance of each diode), which depends on the diode material properties.

Then, the AC component is given by:

$vO_{AC} = numberofdiodes \cdot \frac{rd}{numberofdiodes \cdot rd + R2} \cdot (vO_{envelope} - average_{envelope})$

With this, vO is simply given by: vO = vO_{DC} + vO_{AC}.

This value should be close to 12V.

Name	**Value**
enveloperipple	2.562498e-01
envelopeaverage	1.424920e+01

Table 1: Ripple and average envelope values

Name	**Value**
regulatorripple	6.729519e-02
regulatoraverage	1.200000e+01

Table 2: Ripple and average regulator values

3 Simulation Analysis

For the simulation, NGSpice was used.

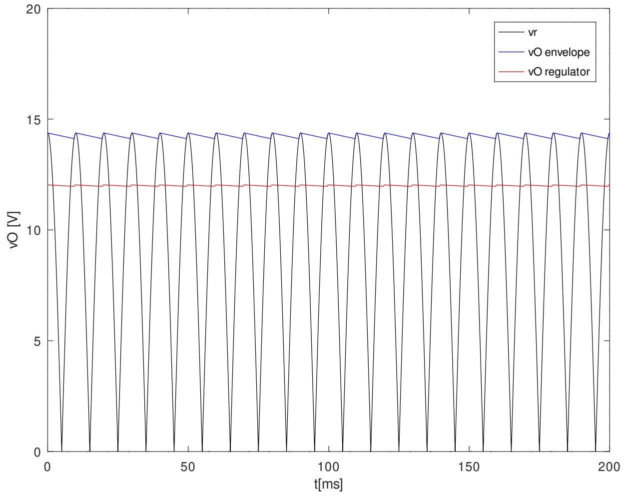

Figure 2: Transformed input voltage, vr, Envelope Detector and Voltage Regulator output voltages

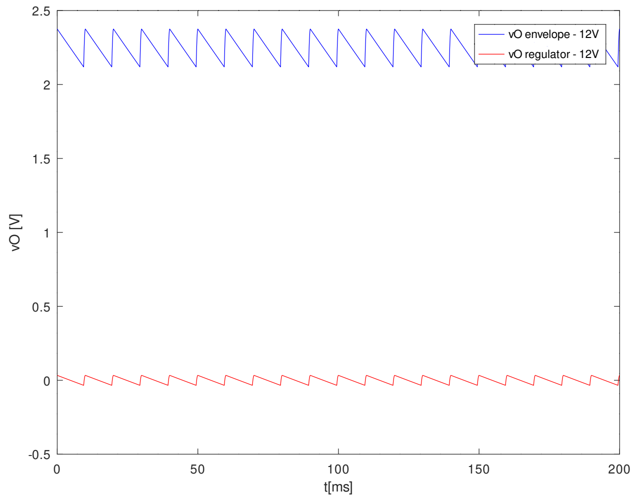

Figure 3: Envelope detector and voltage regulator output voltages deviations around 12V

An ideal transformer model was used, by implementing a dependent current source and a dependent voltage source.

The values of n (dependent sources dependency parameter), the resistance and the capacitance were adjusted throughout the preparation of the assignment in order to achieve the maximum accuracy of the desired output voltage of 12V.

The input voltage of the dependent voltage source, vr, the output voltage of the envelope detector, v(4), and the output voltage of the voltage regulator, v(5), were all computed and are presented in Figure 4.

This data shows the effect of both the envelope and voltage regulators. The former decreases the ripple voltage and the latter keeps the output voltage constant. While v(5) is not completely a straight line (some oscillations are expected due to the non-linear behavior of the diodes), $v(5) - 12V$ is very close to zero, which was ultimately the main goal of this assignment.

As one can see in Figure 5, the regulated ripple voltage has decreased when compared to the envelope ripple voltage, which indicates that the circuit is operating as expected.

The following tables show various values of interest:

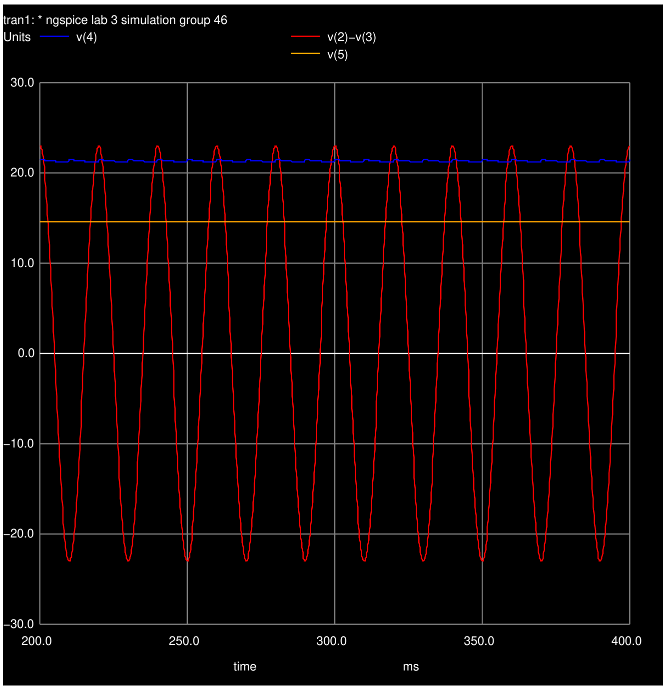

Figure 4: Input voltage of the dependent voltage source, vr, output voltage of the envelope detector, v(4), and output voltage of the voltage regulator, v(5)

4 Results Comparison

As can be seen bellow, there are some differences between the NGSpice and Octave values for the average and ripple voltages of the envelope detector.

These differences relate to the fact that the diodes used are non-linear components. This means that any linear relations established between currents and voltages are approximations of the real circuit, which contributes to some discrepancies between results.

Despite that, these discrepancies are expected, justified and small, which leads us to conclude that this model for the envelope detector is valid and yields a high precision.

In a similar manner, some differences between the NGSpice and Octave values for the average and ripple voltages of the voltage regulator were found, as can be seen bellow.

These discrepancies can be explained by the same aforementioned reasons, namely the non-linear behavior of the diodes used. However, we can conclude that the model used was successful, because it achieved the main goal of producing an output voltage of approximately 12V.

Finally, the cost and merit of this circuit can be found in Table 9.

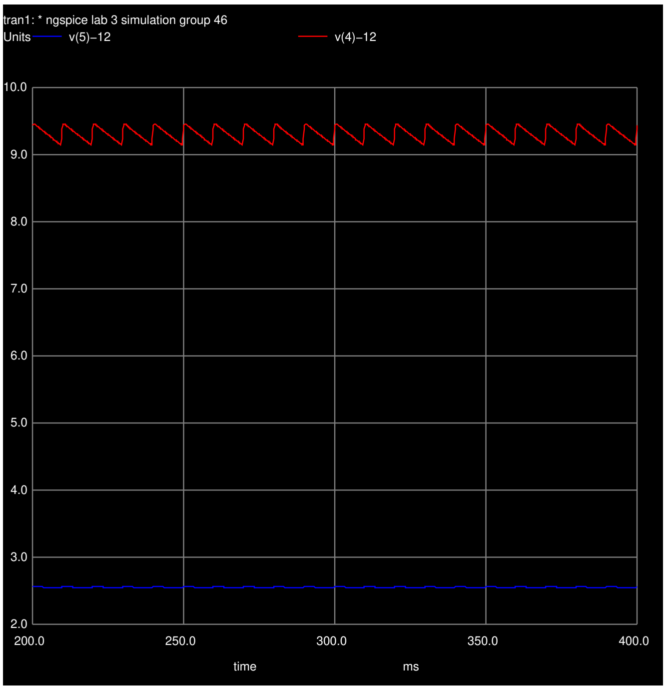

Figure 5: $v(4) - 12V$, $v(5) - 12V$

5 Conclusion

In this laboratory assignment the objective of creating and analysing an AC/DC converter circuit has been achieved. Analyses have been performed both theoretically using the Octave maths tool and by circuit simulation using the Ngspice tool. The simulation and theoretical results differed slightly. This is explained by the non-linear behavior of the diodes that are part of the circuit. Nevertheless, these small deviations did not compromise the goal of this assignment.

To conclude, we believe that the model presented shows a satisfactory precision and thus can be used as an AC/DC converter circuit.

Name	Value [V]
maximum(v(4))-minimum(v(4))	3.137481e-01
mean(v(4))	2.130724e+01

Table 3: Envelope ripple and average voltages.

Name	Value [V]
maximum(v(5))-minimum(v(5))	2.437839e-02
mean(v(5))	1.455071e+01

Table 4: Regulator ripple and average voltages.

Name	Value [V]
enveloperipple	2.562498e-01
envelopeaverage	1.424920e+01

Table 5: Octave envelope ripple and average voltages.

Name	Value [V]
maximum(v(4))-minimum(v(4))	3.137481e-01
mean(v(4))	2.130724e+01

Table 6: NGSpice envelope ripple and average voltages.

Name	Value [V]
regulatorripple	6.729519e-02
regulatoraverage	1.200000e+01

Table 7: Octave regulator ripple and average voltages.

Name	Value [V]
maximum(v(5))-minimum(v(5))	2.437839e-02
mean(v(5))	1.455071e+01

Table 8: NGSpice regulator ripple and average voltages.

Name	Value
1/ (515.8* ((maximum(v(5))-minimum(v(5))) + abs(mean(v(5)-12)) + 10e-6))	7.528792e-04

Table 9: Merit figure