Circuit Theory and Electronics Fundamentals

Instituto Superior Técnico, Universidade de Lisboa

T3: AC/DC Converter Circuit

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1 Introduction

AC Power is the most commonly used type of electricity, having gained popularity over DC during the latter half of the 19th century. However, many equipments require DC for it's operation, specifically devices that use batteries, such as computers or cellphones. Therefore, it is necessary to convert the AC Power obtained either by an alternator (as in the case of a car) or the power grid, to DC. This process is achieved trough the use of a Rectifier or AC/DC Converter. (In the case of Portugal and most of Europe the power grid runs on 230 V / 50 Hz.)

The objective of this laboratory assignmente is to model the AC/DC Converter, shown im Figure 1. This circuit is made up of:

- Transformer: the element of the circuit responsible for converting AC to DC Power.
- Envelope Detector: which "smothens" the original pulsed DC signal.
- Voltage Regulator: which reduces the voltage, keeping it close to the 12V target.

In this lab, the Theoretical Analysis is done in Section 2, the Simulation Analysis in Section 3, the results are compared in Section 4. The Conclusion is presented in Section 5.

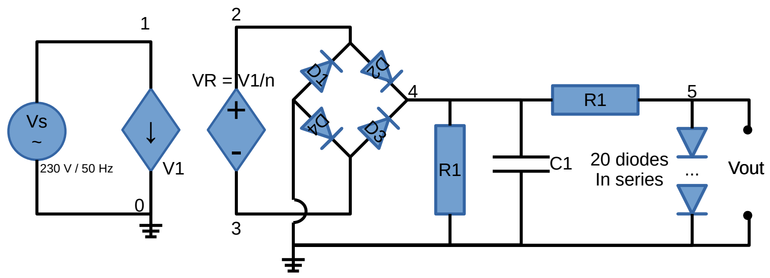

Figure 1: The AC/DC converter on which this report is based

2 Theoretical Analysis

Since the input voltage is Vs = 230V but the desired output is 12V, we used a tranformer to reduce the voltage to the desired value, given the expression Vr = Vs/n, with n = 10. However, we still have to conver the Alternated Current into Direct Current. To do this, the circuit shown in Figure 1 was used.

This circuit is composed by three main subcircuits, already meantioned in the introduction.

The four diodes numbered from 1 to 4 form the Full-Wave Rectifier. They have the function of converting the AC voltage into direct current, by allowing only for a unidirectional flow, as show in green in Figure 2. This is equal to the absolute value of Vr.

The capacitor is utilized to reduce the magnitude of the voltage, making it closer DC voltage and reducing the "ripple", 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,the 20 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 we used NGSpice was used.

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 during the preparation of the assignment in order to achieve the maximum accuracy of the desired output voltage.

in Figure 5 we can see 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).

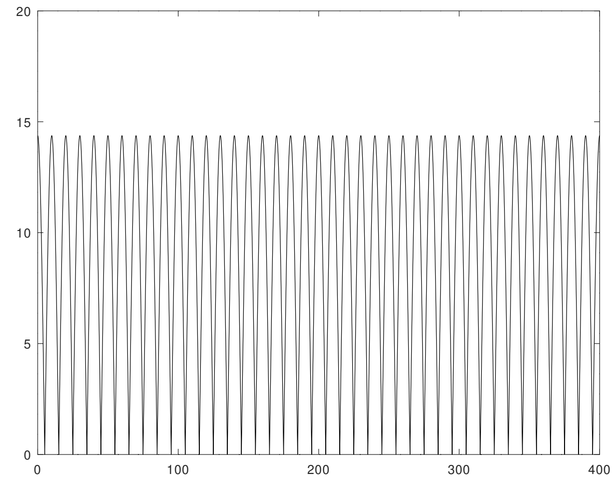

Figure 2: Transformed input voltage, vr

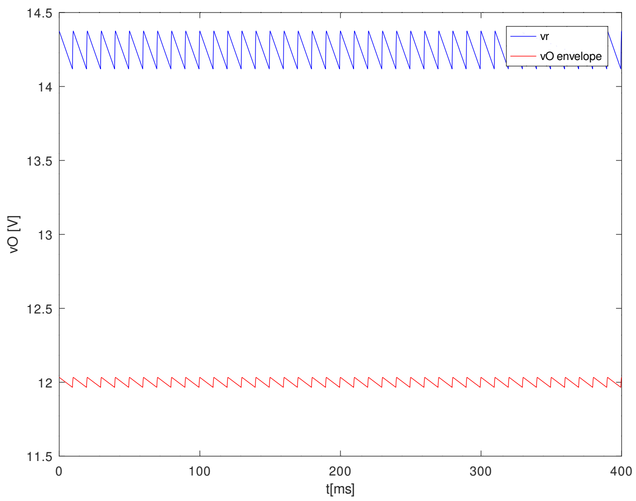

Figure 3: Envelope Detector and Voltage Regulator output voltages

Here we can see the effect of the envelope and voltage regulators. As anticipated in the Theoretical Analysis, the first decreases the ripple voltage and the second keeps the output voltage constant. Even if V(5) is not a perfect DC voltage (we can note some oscillations, which are expectedm, due to the non-linear behavior of the diodes), $V(5) - 12V$ is very close to zero, which is what is expected in a real life rectifier and the goal of the lab.

As we can see in Figure 6, the regulated ripple voltage is far less than the envelope ripple voltage, which indicates that the circuit is operating as expected.

The following tables show various values of interest:

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.

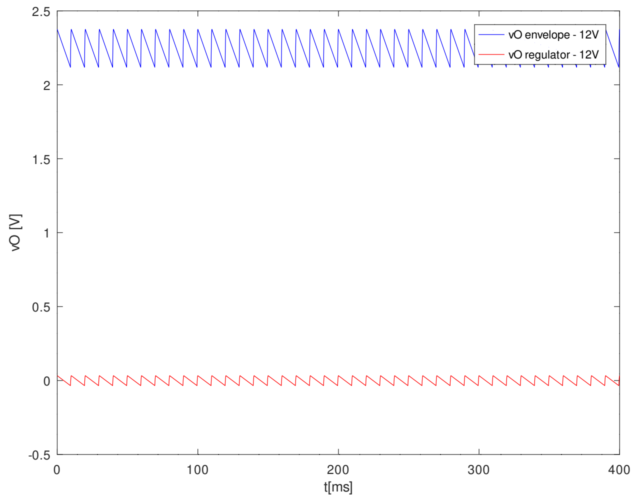

Figure 4: Envelope detector and voltage regulator output voltages deviations around 12V

Name	Value [V]
maximum(v(4))-minimum(v(4))	3.178939e-01
mean(v(4))	2.130513e+01

Table 3: Envelope ripple and average voltages.

Name	Value [V]
maximum(v(5))-minimum(v(5))	1.933408e-02
mean(v(5))	1.331470e+01

Table 4: Regulator ripple and average voltages.

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.

5 Conclusion

In this laboratory assignment the objective of creating and analysing an AC/DC converter circuit has been achieved with success. We have performed theoreticall and simulation analysis, using the Octave for the former and Ngspice for the latter.

We found some discrepancies between both sets of results, which can be atributed to the non-linear behaviour of the diodes. Nonetheless, this discrepancies can also be expected in real life, given that ideal diodes do not exist. Also, those small variations did not compromise the objective of the lab.

We also believe that, given the satisfactory results obtained by us, the model used could be applied in a real life AC/DC rectifier.

Finally, this assignment allowed us to gain some knowledge on AC and DC and how to convert from the first to the second.

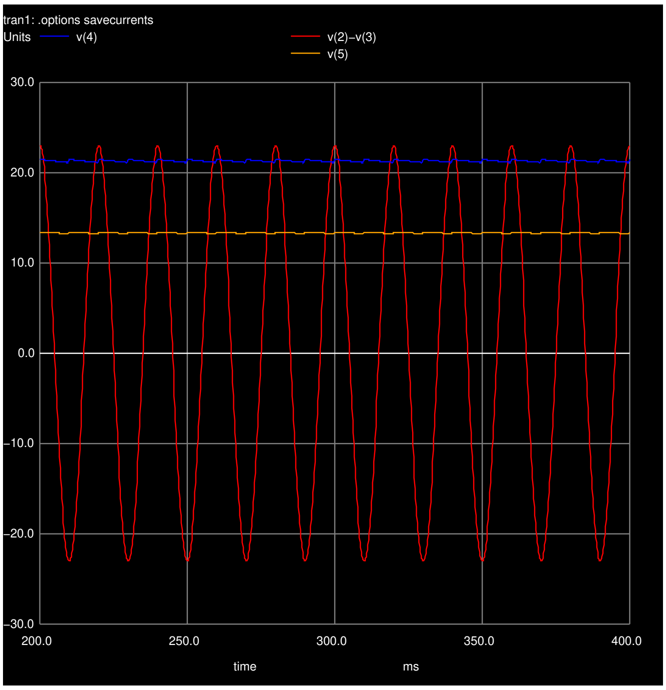

Figure 5: Plot of the computed voltages

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

Table 5: Octave envelope ripple and average voltages.

Name	Value [V]
maximum(v(4))-minimum(v(4))	3.178939e-01
mean(v(4))	2.130513e+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))	1.933408e-02
mean(v(5))	1.331470e+01

Table 8: NGSpice regulator ripple and average voltages.

Name	Value
((1/(maximum(v(5))-minimum(v(5)))) + (1/abs(mean(v(5)-12))))/509	1.031095e-01

Table 9: Merit figure

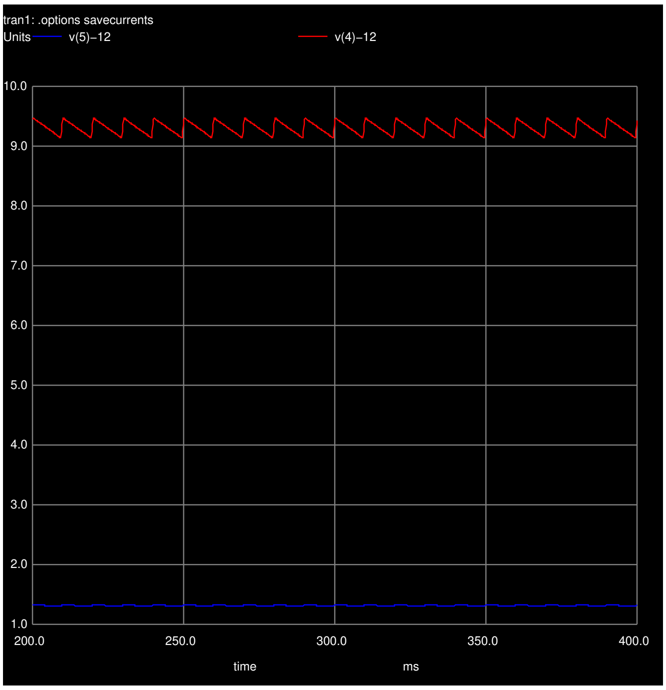

Figure 6: $v(4) - 12V$, $v(5) - 12V$