Circuit Theory and Electronics Fundamentals

T2

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1 Introduction

The objective of this laboratory assignment is to study an AC/DC converter circuit, designed by the group. One can see the circuit in the figure 1, consisting in a full wave rectifier composed of 4 diodes, an envelope detector and a voltage regulator made of a resistor and 20 diodes in series, keeping the voltage at about 12V. A comparison will be done between the NgSpice simulation and the theoretical analysis of the circuit.

The main objective will be to further learn about both methods of analysis, learning about their similarities, differences and which positive and negative sides each of them have.

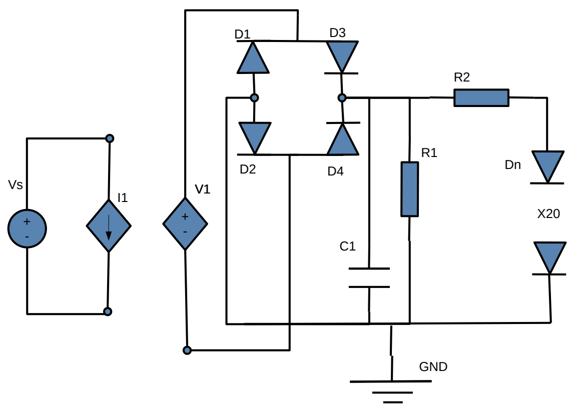

Figure 1: Designed Circuit

In Section 2, a theoretical analysis of the circuit is presented. In Section 3, the circuit is analysed by simulation with NgSpice. In Section 4, the conclusions of this study are outlined and a comparison between the results obtained in Section 2 and Section 3.

2 Theoretical Analysis

Firstly, we used a transformer with the objective of lowering the input voltage of 230V, so that the voltage regulator could then turn that value into an voltage around 12V in order to be outputed. Added to this, it is also necessary to take into consideration that the input current is alternate and that the output has to conduct Direct Current. TO make the shift between the two, we used:

1: A full wave rectifier, which is meant to transform AC into an unidirectional current, with constant amplitude. In order to mathematically achieve this, we used the absolute value of the sinusoidal function created by the output function: V_r

2: A capacitor that reduces the voltage magnitude, rounding it to DC. In octave, we divided the times in which the diodes were ON and OFF, given that:

$$t_{OFF} = \frac{1}{w} arctan(\frac{1}{wR_1C}). \tag{1}$$

For $t < t_{OFF}$, $V_O = V_r$, and for $t > t_{OFF}$:

$$V_O = V_s cos(wt_{OFF}) exp(-\frac{t - t_{OFF}}{R_1C}), \tag{2}$$

because of the presence of the capacitor. The ripple voltage will then be the difference between the maximum and minimum values of V_0. We then renamed it V_{OENV}.

3: A series of 20 diodes to perfect the DC. The data from **2:** also allows for the calculation of V_{0AVG}, the average value of V_0. This values lets us know if the voltage drop between V_5 and V_0 is within the boundaries of what can be handled by the series of diodes. Given that these values are calculated from the DC, in order to obtain the same values for the AC, the following expression needs to be applied:

$$V_{OAC} = ndiodes \frac{R_D}{ndiodes R_D + R_2}(V_{OENV} - V_{OAVG}), \tag{3}$$

in which R_D is the resistance of each diode.

Ripple Envelope	4.315587e+00
Average Envelope	1.712652e+01
Ripple Regulator	7.367972e-01
Average Regulator	1.200000e+01

Table 1: Ripple and Average Voltages for Envelope and Regulator

The merit of the work theorized in this analysis was calculated through a simple form represented in 4

$$M = \frac{1}{cost(ripple(v_0) + average(v_0 - 12) + 10^{-6}} \tag{4}$$

where $cost$ respresents the cost of resistors, capacitors and diodes in the circuit.

The value computed was 3.44×10^{-2}, which was lower than what was expected, meaning the circuit could have been more optimized. However, it was felt that the value was satisfying for the purpose of this assignment.

Merit	3.444730e-02

Table 2: Merit calculated through Octave

The following plot shows the voltage of the transformer, the voltage of Envelope Detector and Voltage Regulator.

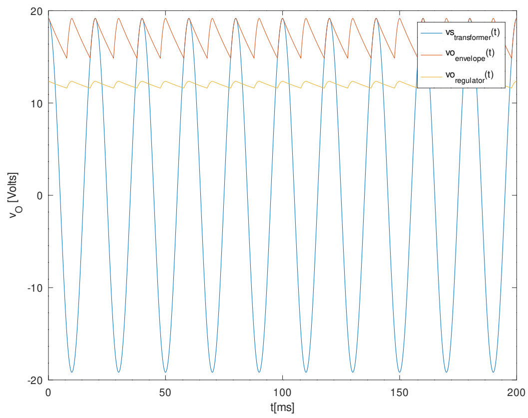

Figure 2: Voltage of the rectifier, Voltage of Envelope Detector and Voltage Regulator

Then, the Deviation from the desired DC voltages was also plotted.

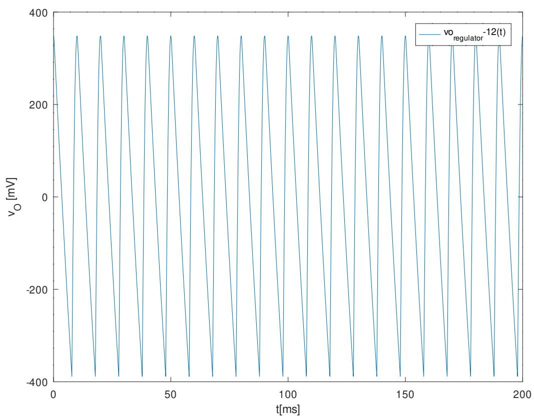

Figure 3: $v_0 - 12$ (Deviation from the desired DC voltages)

3 Simulation Analysis

A software called NGSpice was exploited to simulate the AC DC converter. It is important to note that some changes were made to the circuit, from the get-go, for simplification purposes.

The following table shows the results computed by the simulation: the input voltage of the secondary circuit (v(2)), the ouput voltages of the Envelope Dectector and the Voltage Regulator (v(4) and v(5), respectively).

rippleenvelope	4.124405e+00
averageenvelope	1.583303e+01
rippleregulator	5.507136e-01
averageregulator	1.211278e+01

Table 3: Ripple and Average Voltages for Envelope and Regulator

The value computed for Merit was 4.03×10^{-2}, which was lower than what was expected, meaning the circuit could have been more optimized. However, it was felt that the value was satisfying for the purpose of this assignment.

merit	4.029838e-02

Table 4: Merit calculated through NgSpice

The following plot shows the voltage of the transformer v(2)-v(3), the voltage of Envelope Detector v(4) and Voltage Regulator v(5).

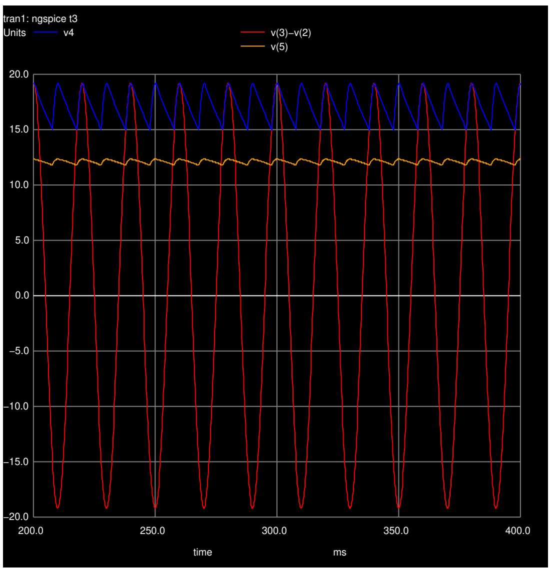

Figure 4: Voltage of the rectifier, Voltage of Envelope Detector and Voltage Regulator

Then, the Deviation from the desired DC voltages was also plotted. The variable v(5) corresponds to v_o

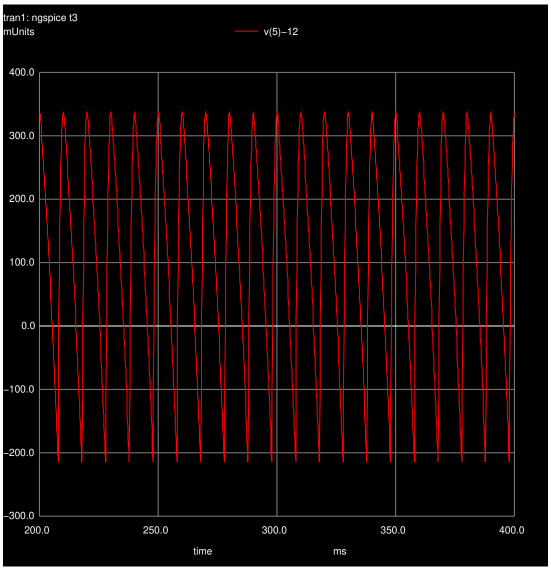

Figure 5: $v_0 - 12$ (Deviation from the desired DC voltages)

4 Conclusion

Now, the graphs and values obtained in Section 2 and Section 3 will be presented side by side and compared.

The tables and graphs corresponding to Theorical Analysis, through Octave, will be presented on the left, while the Simulation ones made with Ngspice will appear on the right.

Firstly, the values of Ripple and Average voltages of both the envelope detector and the voltage regulator can be seen in the following table.

Ripple Envelope	4.315587e+00
Average Envelope	1.712652e+01
Ripple Regulator	7.367972e-01
Average Regulator	1.200000e+01

Table 5: Ripple and Average Voltages for Envelope and Regulator in Theoretical Analysis

rippleenvelope	4.124405e+00
averageenvelope	1.583303e+01
rippleregulator	5.507136e-01
averageregulator	1.211278e+01

Table 6: Ripple and Average Voltages for Envelope and Regulator in Simulation

As can be observed, there is some slight inaccuracy between what was obtained theoretically and through simulation, which probably ocurred due to the natural oscilation in the software used (NGSpice). This can explained by the fact that, in oppostition to what happened in previous assignments, there is one component, the diode, which is non-linear meaning there is no linear correlation between current and voltage. The exponential function used in the equations is most likely the cause of said oscilations.

That said, it is still an accurate enough result to consider the envelope the detector valid, as the output voltage was, successfully, around 12V.

The Merit, calculated through the formula 4 was obtained by both softwares:

Merit	3.444730e-02

Table 7: Merit calculated in Theoretical Analysis

merit	4.029838e-02

Table 8: Merit calculated in Simulation

As for the voltage values, the Merit values also came with a slight inaccuracy. The Merit value is low, but the group couldn't make it higher, however the main objective of the assignment was achieved.

Now let's take a look at the plots done for the output of the Envelope Detector and the Voltage circuits obtained in Theorical Analysis and in Simulation. Also, the comparison between the graphs of $v_o - 12$ (output of AC component plus DC deviation) obtained with Octave and NgSpice.

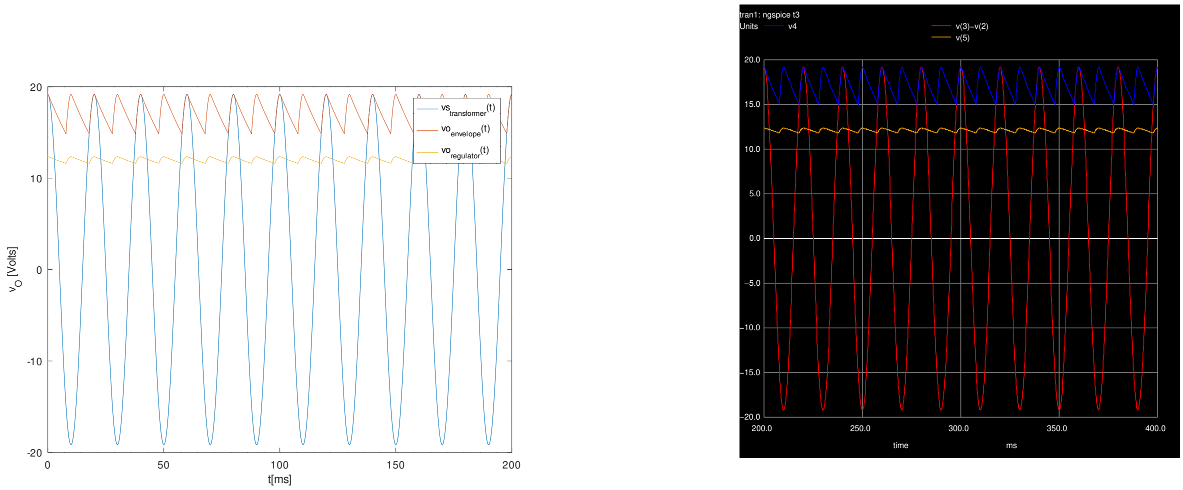

Figure 6: Voltage of the rectifier, Voltage of Envelope Detector and Voltage Regulator (Analysis left vs Simulation right)

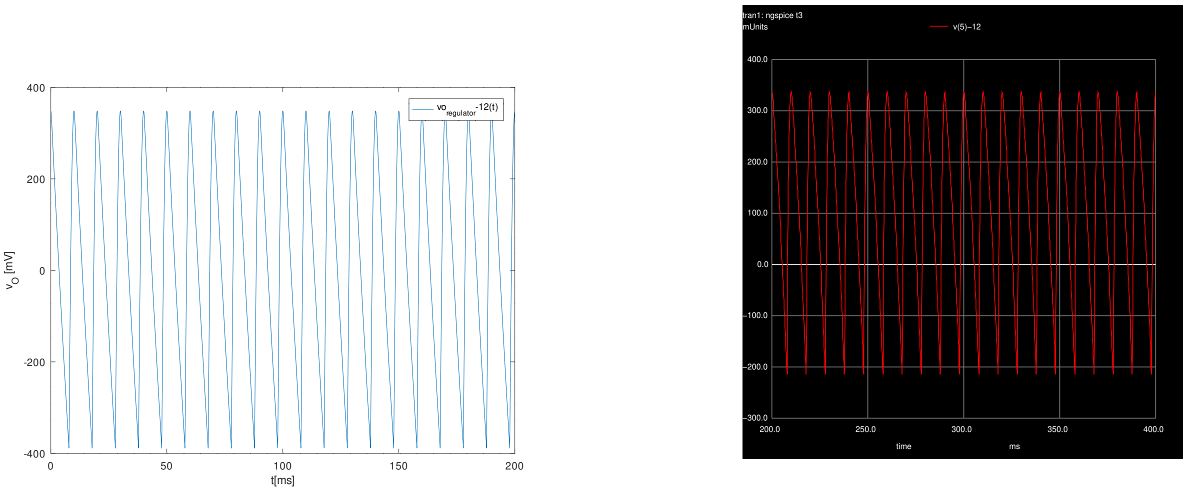

Figure 7: $v_0 - 12$(Analysis left vs Simulation right)

It is clear that both plots are almost identical, which proves the success of the simulation. We can also conclude that the Envelope Detector and Voltage circuits designed by the group worked as expected and theorized when simulated.