Modified Cuk Converter: Analysis and Simulation

The Cuk converter is known in the literature. The Cuk converter may be modified to obtain a Boost converter without changing its kernel structure. The advantage of such modification is that the input and output voltage share a common point with the same electrical potential. Remember that the conventional Cuk converter has tis output voltage positive terminal at the same point of the input voltage source GROUND terminal. This may be inconvenient for some real applications.

In order to surpass this inconvenience, the Cuk is modified. The resulted static transfer characteristic is the same as the Boost converter. Thus, the modification is feasible when the Cuk converter operates as a boost.

Let's see the modification and its analysis.

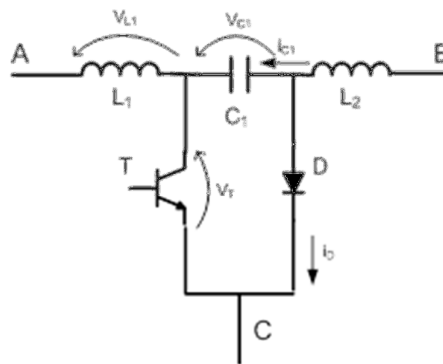The Fig. 1 presents the kernel of the Cuk converter.

Figure 1: The kernel of the Cuk Converter

In the conventional Cuk converter, the input voltage source is connected through point A (+) to C (GND). The output (the capacitor + the load resistor) is connected through the point B to C. The output voltage positive terminal is in the point C and the GND is in the point B.

By modified the location of the output, which means changing the capacitor and the resistor, we reach a Modified Cuk Converter. By keeping the input voltage source unchanged and by placing the output circuit through point A to B, the resulted circuit is presented in Fig. 2. Now, the input and the output voltages share a common point. In this case it is the voltage source positive terminal.
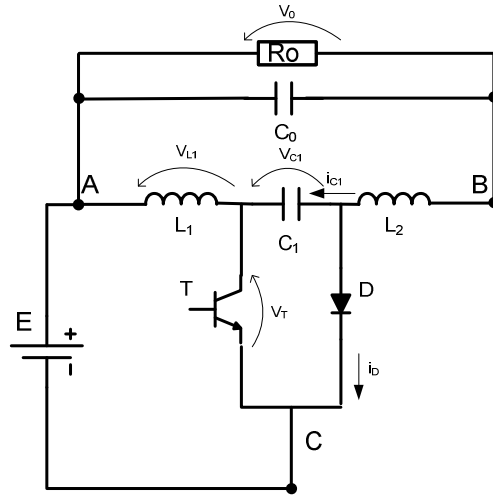
Figure 2: Modified Cuk Converter.

In order to demonstrate that the positive terminals are shared, we begin by the fact that the average current through a capacitor in steady-state is zero. Therefore,

$$i_{C1average} = 0 \tag{1}$$

It results that the average output current must pass through the diode D. Consequentially, the output current is going from point A to B and the output voltage reference is that depicted in the Fig. 2.

Now we must know what is the average C1 capacitor voltage. For such purpose, the Fig. 3 presents a mesh in steady-state condition.
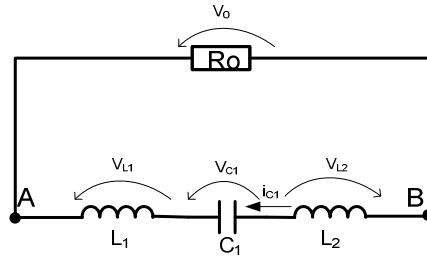

Figure 3: A mesh in steady-state condition.

For the voltage Kirchhoff law,

$$\Sigma V = 0 \tag{2}$$

so,

$$V_O + V_{L2} - V_{C1} - V_{L1} = 0 \tag{3}$$

The average inductor voltages are zero in steady-state. Therefore,

$$\therefore V_{C1} = V_O \tag{4}$$

We also have,

$$i_{C1} = i_{L2} = i_O \qquad (5)$$

Let's consider the Continuous Conduction Mode, the modified Converter has two operation steps.

The first occurs when the transistor is conducting. The Fig. 4 presents the first step equivalent circuit. The voltage Vc1 is counter-applied through the diode, keeping it reversed biased.
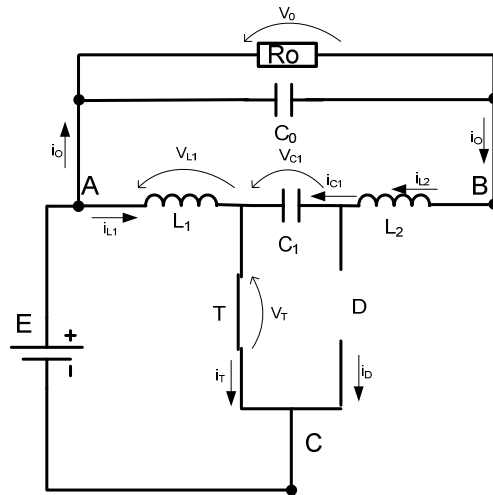

Figure 4: First step equivalent circuit.

The Vak diode voltage is given by (6).

$$V_D = -V_{C1} = -V_O \qquad (6)$$

It is possible to see two distinct meshes during the first step. These meshes are depicted in Fig. 5.
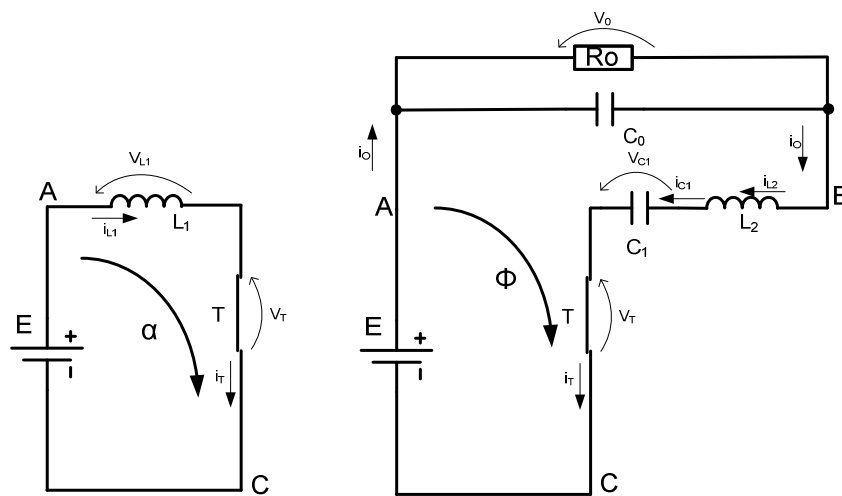

Figure 5: Two distinct meshes for the first operation step.

From the α mesh, it can write:

$$V_{L1} = E \tag{7}$$

From the phi mesh,

$$i_o = i_{L2} = i_{C1} \tag{8}$$

Also,

$$\Sigma V = 0 \tag{9}$$

then,

$$-E + V_o + V_{L2} - V_{C1} = 0 \tag{10}$$

where,

$$V_o = V_{C1} \tag{11}$$

$$\therefore V_{L2} = E \tag{12}$$

The transistor current is the sum of the two meshes, which is given by (13).

$$i_T = i_{L1} + i_o \tag{13}$$

The second step occurs when the transistor is blocked and the diode is conducting. The fig. 6 presents the second step equivalent circuit.
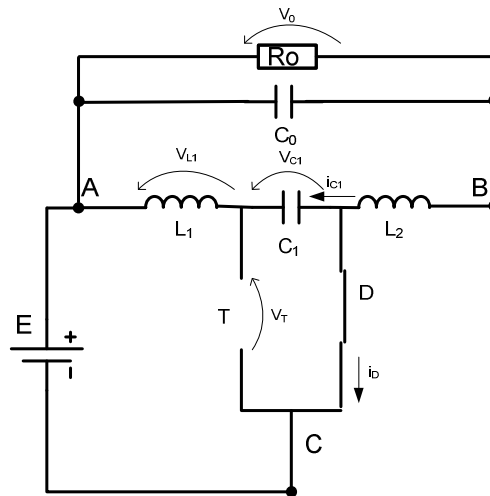

Figure 6: The second step equivalent circuit.

Again, two distinct meshes may be noticed. The Fig. 7 present the two meshes for the second step.
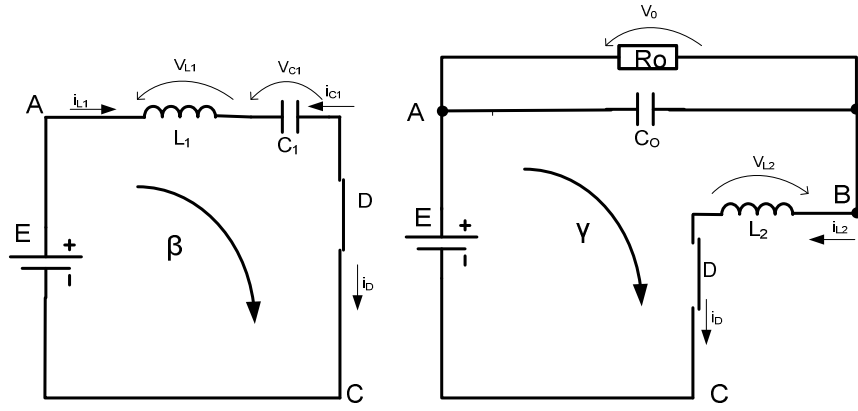
Figure 7: Two meshes for the second step.

From the left circuit:

$$i_{C1} = -i_{L1} \tag{14}$$

The transistor voltage is given by (15).

$$V_T = V_{C1} = V_O \tag{15}$$

Also,

$$\Sigma V = O \tag{16}$$

$$-E + V_{L1} + V_{C1} = 0 \tag{17}$$

$$\therefore V_{L1} = E - V_O \tag{18}$$

Due to the inductor voltage in the first step be higher than zero, it concludes that the same voltage at the second step must be lower than zero. Therefore, we can say:

$$V_O > E \tag{19}$$

From the right circuit,

$$\Sigma V = 0 \tag{20}$$

$$-E + V_O + V_{L2} = 0 \tag{21}$$

$$\therefore V_{L2} = E - V_O \tag{22}$$

The Fig. 8 presents the most relevant waveform of the Modified Cuk.
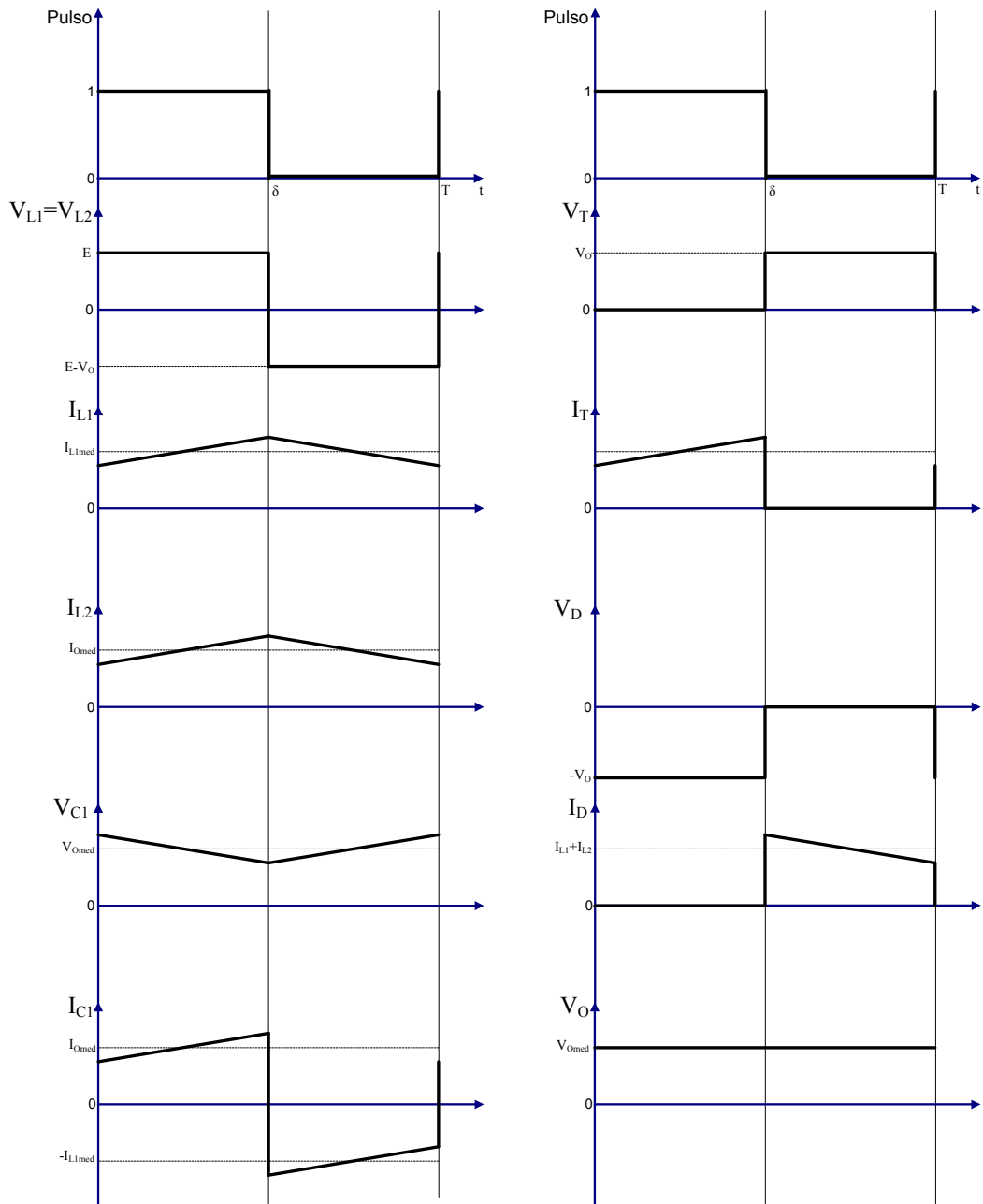
Figure 8: Relevant waveforms for the modified Cuk Converter.

Now it is possible to derive the static transfer characteristic (Vo/E) in function of the duty-cycle (δ). For such purpose the voltage waveform across the inductor L1 is used. The Fig. 9 presents the L1 inductor voltage.
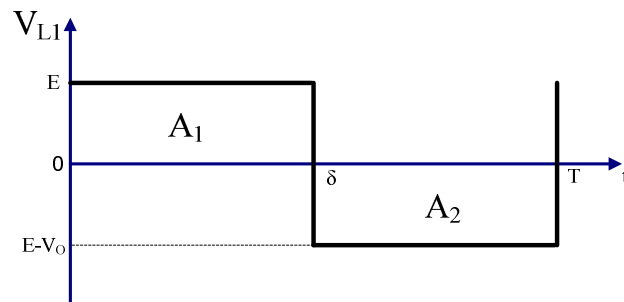

Figure 9: L1 inductor voltage.

In the steady-state condition we have:

$$A_1 = A_2 \tag{23}$$

where,

$$A_1 = \delta \cdot E \tag{24}$$

$$A_2 = (V_O - E) \cdot (1 - \delta) \tag{25}$$

So,

$$\delta \cdot E = (V_O - E) \cdot (1 - \delta) \tag{26}$$

$$\delta \cdot E = V_O - V_O \cdot \delta - E - E \cdot \delta \tag{27}$$

$$\therefore \frac{V_O}{E} = \frac{1}{1 - \delta} \tag{28}$$

The static transfer characteristic is the same of a Boost converter.

Example)

The following initial values are given.

$$E = 100V \tag{29}$$

$$V_O = 150V \tag{30}$$

$$P_i = 500W \tag{31}$$

The duty-cycle is shown in (32).

$$\delta = 0,33 \tag{32}$$

The average input current is given by (33).

$$i_{in\_med} = \frac{P_i}{E} \tag{33}$$

therefore,

$$i_{in\_med} = 5A \tag{34}$$

By considering a lossless converter, the output power is equal to the input power:

$$P_O = P_i \tag{35}$$

In a different way:

$$E \cdot i_{in\_med} = V_O \cdot i_{O\_med} \tag{36}$$

therefore,

$$i_{O\_med} = 3,33A \tag{37}$$

By applying the current Kirchhoff law at the point **A,** the equation (38) is obtained..

$$i_{in\_med} = i_{O\_med} + i_{L1\_med} \tag{38}$$

So,

$$i_{L1\_med} = 1,37A \tag{39}$$

Equally to the point **B**:

$$i_{L2\_med} = i_{O\_med} \tag{40}$$

Therefore,

$$i_{L2\_med} = 3,33A \tag{41}$$

The voltage that the diode must hold is given by (44).

$$V_D = -V_O \tag{42}$$

therefore

$$V_D = -150V \tag{43}$$

The equations (46) to (49) presents the minimum values to be adopted by the passive elements it the Cuk converter in order to it operate in the continuous conduction mode.

$$C_{1min} = \frac{I_{O\_máx} \cdot \delta \cdot (1-\delta) \cdot \tau}{2 \cdot E} \tag{44}$$

$$L_{1min} = \frac{E \cdot \tau \cdot (1-\delta)}{2 \cdot I_{O\_min}} \tag{45}$$

$$L_{2min} = \frac{E \cdot \delta \cdot \tau}{2 \cdot I_{O\_min}} \tag{46}$$

$$C_O = \frac{E \cdot \delta \cdot \tau^2}{8 \cdot L_2 \cdot \Delta V_O} \tag{47}$$

where,

τ is the switching period

Simulation Results)

The following table presents the simulation parameters:

Parameters	Value
Input Voltage (E)	100V
Input Power (Pin)	150W
Switching frequency (fs)	10kHz
Output current ripple (ΔIo)	10% de Io
Output voltage ripple (ΔVo)	5% de Vo

The following table presents the calculated values according to equations (46) to (49).

Parameters	Value
C_{1min}	382nF
L_{1min}	2mH
L_{2min}	1mH
C_O	5,5uF

For the simulation , the following values were adopted.

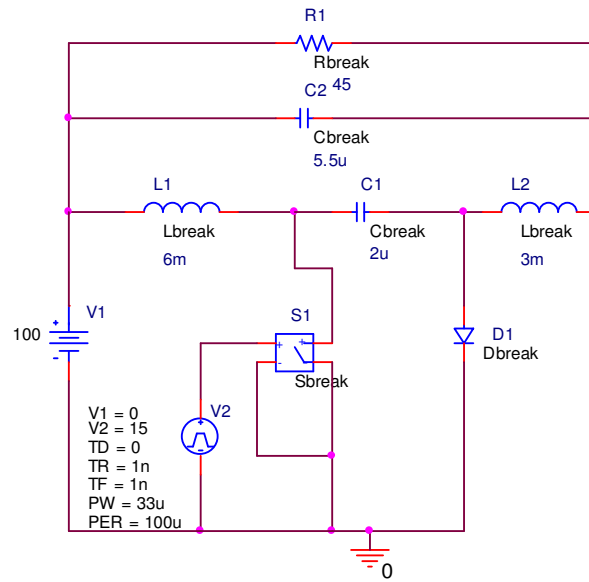| Parameters	Valor
C_1	2uF
L_1	6mH
L_2	3mH
C_O	5,5uF

The Fig. 10 presents the simulated circuit.

Figure 10: Simulated Circuit

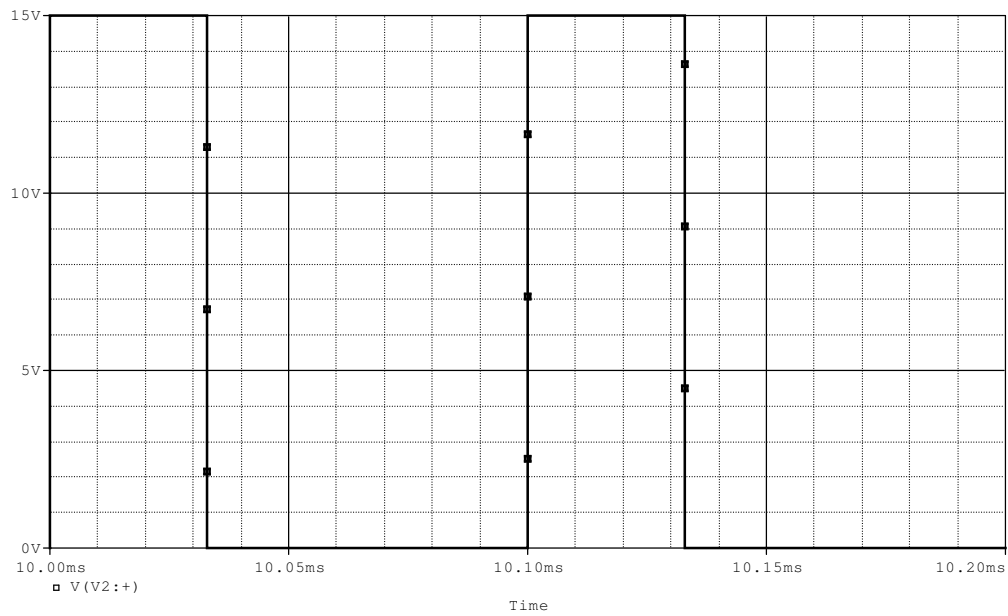The Fig. 11 presents the transistor gate signal.

Figure 11: Transistor gate signal.

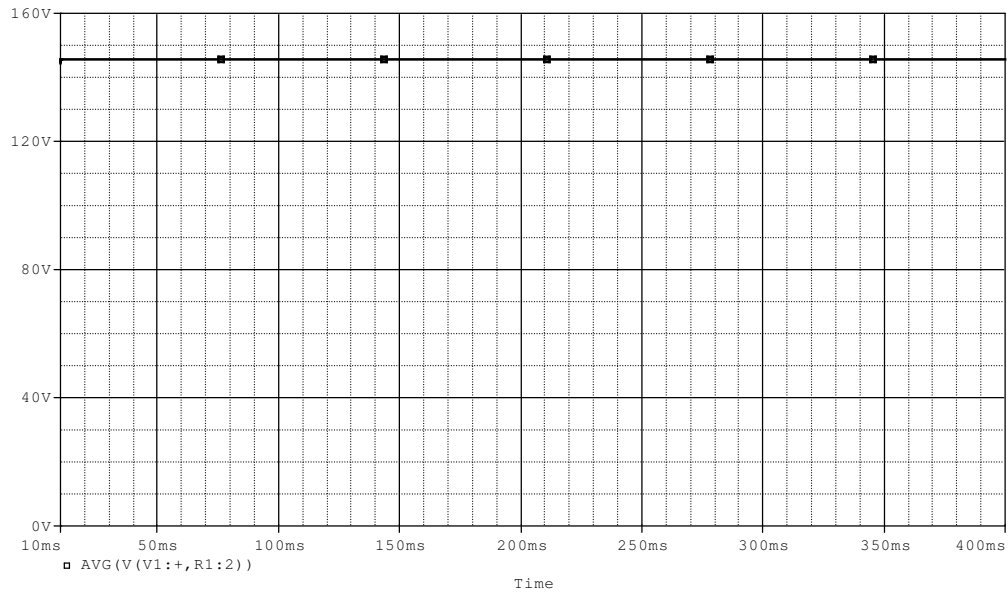The Fig. 12 presents the output voltage, which correspond to approximately 150V.

Figure 12: Output voltage.

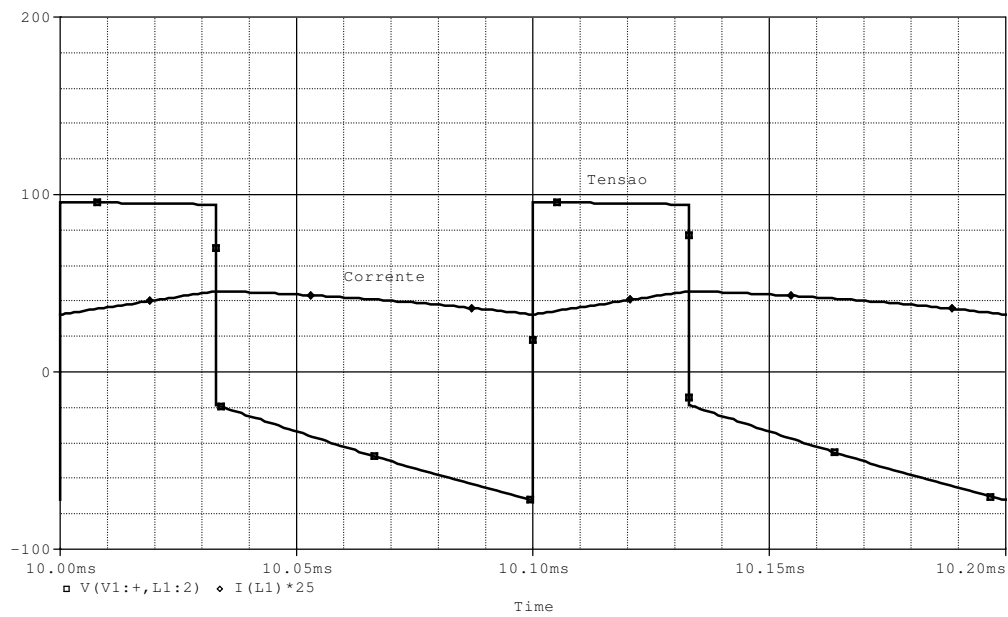The Fig. 13 presents the voltage and current across the L1.

Figure 13: Current and Voltage across the L1 (where is written "corrente" it reads current and where is written "Tensao" it reads voltage)

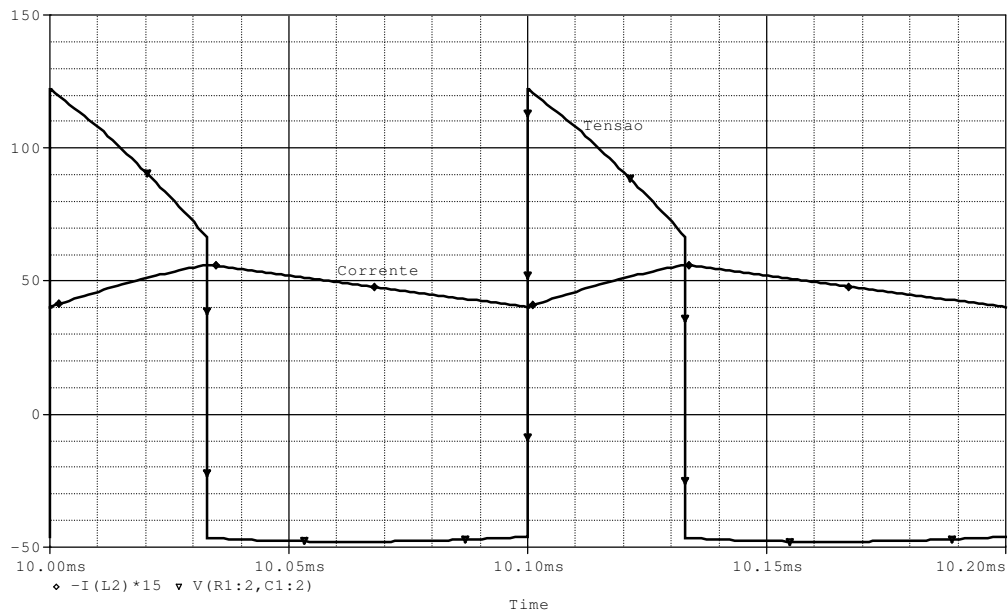The Fig. 14 presents the voltage and current across the L2.

Figure 14: Current and voltage across the L2. (where is written "corrente" it reads current and where is written "Tensao" it reads voltage).

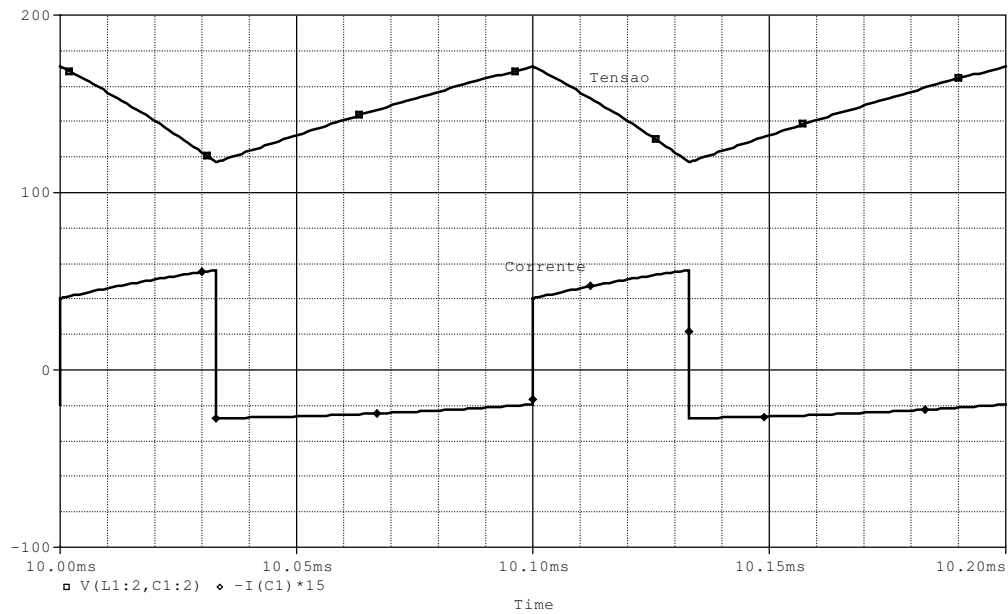The Fig. 15 presents the voltage and current across the C1.

Figure 15: Current and voltage across the C1 (where is written "corrente" it reads current and where is written "Tensao" it reads voltage).
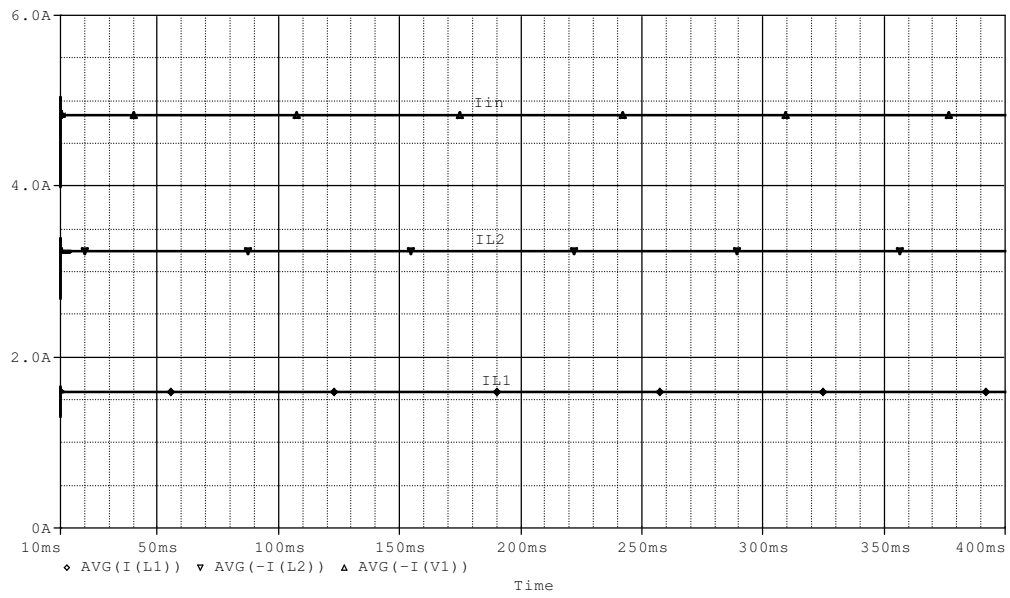
The Fig. 16 presents the average values through the L1, L2 and Iin.

Figure 16: Average values through the L1, L2 and Iin.