

High frequency isolated boost converter for application in PV systems

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Abstract – In this paper a high frequency power electronics conversion system is used to connect a PV panel to the power grid. The proposed system is sized, the controllers are designed and simulated.

A DC-DC converter allowing the conversion from the direct current (that is obtained through the photovoltaic panel) to a higher DC voltage is used. Then, DC / AC converters are used in the connection to the high frequency transformer and to the grid, using different modulation approaches. A MPPT algorithm is tested for two different operating scenarios: in the first one, a constant irradiance is introduced in order to verify if the system behaves as expected. In the second test a variation of solar irradiance is imposed.

The obtained results show that the proposed system is able to inject sinusoidal currents in the grid, guaranteeing MPPT operation.

Index Terms—Photovoltaic panel, voltage control, current control, inverter.

I. INTRODUCTION

The use of solar PV systems has been proving to be a very interesting alternative to complement the generation in the electric power system. The use of PV systems, once attractive mainly in remote regions or in rural areas, is increasingly being used in urban applications, namely in homes [1] with small single-phase units of electricity production connected to the grid.

PV systems have several benefits as: low maintenance, long lifespan, the fact that they are not noisy, their vast and easy applicability and also because they are an inexhaustible source of energy.

In order to obtain the highest yield of solar energy, photovoltaic panels must operate at their maximum power point. For this, an algorithm is used, usually called MPPT (Maximum Power Point Tracking), which puts the photovoltaic panel operating at its maximum power point, using an electronic DC-DC power converter. In this way, losses resulting from environmental conditions such as: shade zones and little solar radiation can be reduced throughout the day. This adaptation to the variations of the irradiation results in the constant change of the instantaneous power [2].

In order for the DC voltage of the photovoltaic panel to be converted to AC voltage, an inverter is used. The inverting process consists of supplying an alternating voltage or alternating current at the output of the inverter, from a direct voltage as input.

In order for the DC voltage of the PV array to be converted to AC voltage, an inverter is usually used to

convert a voltage or DC current to an AC voltage / current. Currently, in most applications this conversion is performed using IGBT transistors and Pulse Width Modulation (PWM) modulation processes to reduce the harmonic contents of the AC currents.

In this work the connection between the panel and the network will be made through a high frequency transformer, in order to guarantee galvanic isolation and also to ensure that the transformer has a significantly smaller dimension than a transformer of equal power, but working at the grid frequency.

In figure 1 we can observe the general scheme of the system sized and simulated in this paper.

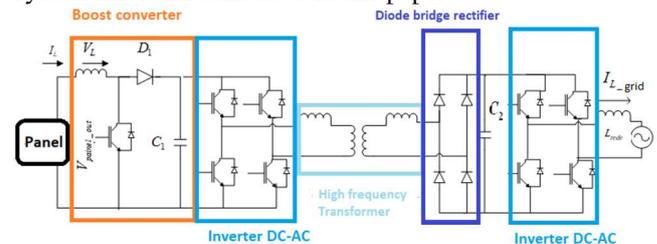


Fig. 1 - General scheme of the proposed photovoltaic system

II. PROPOSED SYSTEM

A. PV panel

The photovoltaic panel is used to convert solar energy into electrical energy. It consists of photovoltaic modules and these, by photovoltaic cells, constituted by a thin layer of material type N (material that has free electrons) and another with material type P (material that has free positive charges, called gaps) thus forming the cells of PN junction. At this junction an electric field is created that separates the charge carriers that reach it: the electrons, excited by the photons with enough energy to move electrons from the valence band to the conduction band, are accelerated to a negative terminal, while the gaps are directed to a positive terminal, thereby connecting the panel terminals to a circuit that is externally closed through a load.

This effect called photovoltaic effect is an existing phenomenon in certain materials that have the capability to produce electric current when exposed to light. Its discovery dates back to 1839 and is attributed to a French physicist named Alexandre Edmond Becquerel [3].

Figure 2 represents the simplified model that will be used in this study.

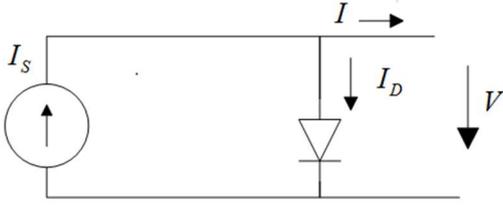


Fig. 2. Model one diode and three parameters.

Table 1 shows the data supplied by the manufacturer, [4]:

Table 1 - Data provided by the manufacturer.

Data provided by the manufacturer	
P_{pico} [Wp]	260
N_s	60
θ_m [$^{\circ}$ C]	45
V_{MP} [V]	32,35
I_{MP} [A]	8,04
V_{CA} [V]	38,49
I_{CC} [A]	8,56

From the data sheet of the manufacturer of the photovoltaic module, it is possible to determine the three parameters (m, I_0, I_s), necessary to represent the model of the photovoltaic panel.

The variable that represents the number of modules considered is defined as X_{module} .

The operating conditions are considered as $G=800$ W/m^2 and $T=45^{\circ}C$. Table 2 shows the values obtained for the STC conditions.

Table 2 - Values obtained for the STC conditions

values obtained for STC conditions	
V_T [V]	0,0274
V_T' [V]	0,0257
V_{CA} [V]	99,198
V_{MP} [V]	77,344
I_{MP} [A]	6,328
I_0^r [A]	2.026×10^{-7}
I_0 [A]	$1,925 \times 10^{-6}$
I_{CC} [A]	6,848
m	239,652
X_{module}	3

B. MPPT Algorithm

In order to extract the maximum power that the PV module can produce, a Maximum Power Point Tracking (MPPT) algorithm needs to be used. It is known that this point changes throughout the day and is subject to variations in irradiance and ambient temperature. The

algorithm is designed so that the system operates most of the time at the point of maximum power.

There are several methods for calculating MPPT, although the most used are the Perturbation and Observation (P & O) method or the Incremental Conductance (IC) method [5].

The P & O method is implemented in the following way: a periodic disturbance is made, that is, the voltage is increased or decreased (V_{panel_out}), or the panel output current (I_{panel_out}), and a new calculation is made to obtain the new power value $P_{out}(x)$, which is compared to the previous power value $P_{out}(x-1)$. The basic idea of the algorithm is that if a voltage or current disturbance, as previously mentioned, changes the power to a larger value, in the following iteration, the change of the operating point is made in that direction. In case of a decrease in the power value, the operating point changes in the reverse direction.

This method requires relatively low processing, since it uses only functions of comparison, subtraction and summation as can be observed in the flowchart of figure 3.

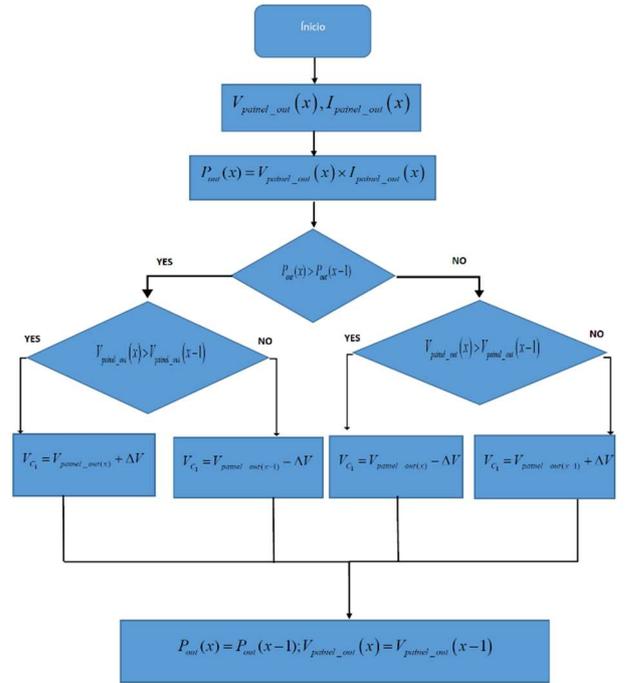


Fig. 3 - Flowchart of the algorithm to calculate MPPT by the method of Disturbance and Observation.

C. DC-DC converter

The PV panel is connected to a DC-DC converter ("step-up converter" or "Boost converter"), in order to obtain in the output of the panel, a voltage increase to a value that ensures correct operation of the system in the connection to the power grid. The semiconductor is switched through the MPPT system depending on the increase or decrease of the PV panel output voltage.

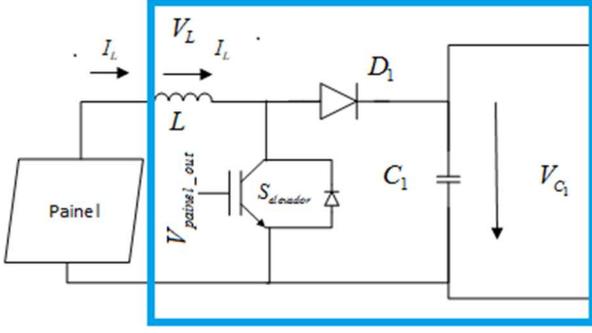


Fig. 4 - Connection of PV panel to the boost converter

$$I_L = \frac{P_{peak}}{V_{panel}} \quad (1)$$

To size the inductor it is assumed that the maximum value ΔI_L of the current ripple is 10% of its average value.

$$L = \frac{\delta V_{painei_out}}{f_c \Delta I_L} \quad (2)$$

The capacitor C_1 is sized taking into account the power variation and the time interval Δt , which represents the period in which there is a voltage variation in the capacitor between the value V_{C1_max} and V_{C1_min} .

$$C_1 = \frac{2P_0 \Delta t}{V_{C1_max}^2 - V_{C1_min}^2} \quad (3)$$

In the topology under study a high frequency transformer is used, which guarantees galvanic isolation, with relatively low volume [6], when compared to a transformer of the same power operating at 50Hz. The high-frequency transformer will operate at a nominal frequency much higher than 50 or 60 Hz, characteristic values of conventional transformers.

D. High frequency transformer

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E. Converters topology

For this study, single-phase bridge converters made up of IGBT transistors. The use of the IGBT transistors is mainly due to their ability to operate in frequencies in the order of tens of kHz, for the powers in question.

F. Single-phase full bridge inverter with three-level PWM control

To control the converter that is connected to the power grid, a three-level pulse width modulation was adopted, and is represented in figure 5.

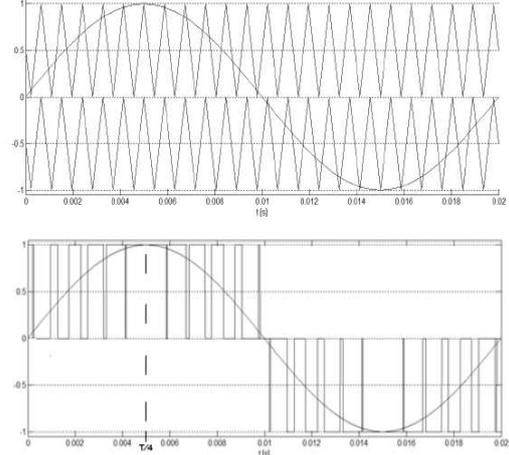


Fig. 5 - Three level PWM

This modulation allows to minimize the filtering components, as well as to guarantee lower harmonic content.

This modulation works as follows: whenever the modulating wave is higher than the two carriers the output voltage is always positive; in case the modulating wave is found to be contained between the two carrier waves, this means that the output voltage is zero.

Finally when the modulating wave is lower than the two carriers then the voltage obtained at the output is negative.

A switching frequency of 20 kHz was defined, ensuring that the carrier frequency is much higher than the modulator frequency, since the grid frequency is 50 Hz.

III. CONTROL OF THE SYSTEM

A. Capacitor voltage control

In order for the system to work correctly, it is necessary to ensure the voltage control in the capacitor, since the controller response determines the value of the modulator of the inverter connected to the high frequency transformer.

As it is not necessary to guarantee that the capacitor voltage is exactly equal to its reference value on the DC stage, a P (proportional) controller is used, which may cause a static error. However, this error will not be critical, since it can be easily compensated by the following converters, thus not affecting the current to be injected into the grid.

The block diagram of the voltage controller in the capacitor C_1 is shown in 6.

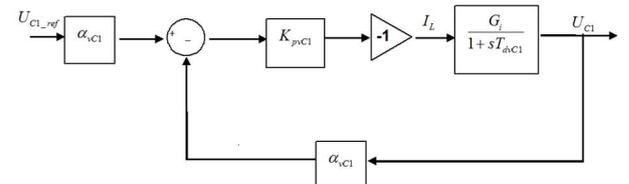


Fig. 6 – Diagram block of the capacitor voltage proportional controller.

Table 3 shows the values of the voltage controller in capacitor C_1 .

Table 3 - Values obtained for the voltage controller in C_1

α_{vC1}	T_{dC1}	$P_{pico}[W]$	$U_{C1}[V]$	Kp_{vC1}
0,01	2.5×10^{-5}	780	120	80

B. Control of grid currents

In order to control the mains current, a reference value is required. In this case, the reference value is given by the product between the power of the MPPT on the secondary side of the transformer, since losses in the power converters are considered negligible.

The inverter is controlled in closed chain, as shown in figure 7, in order to ensure that the mains current follows the reference that is imposed.

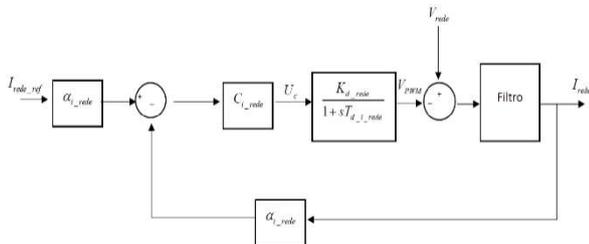


Fig. 7 - Block diagram of the grid current controller.

The control is done using a PI compensator, in order to guarantee a relatively fast response (proportional component) and a static null error (integral component).

Table 4 - Values obtained for the current controller.

K_{p_rede}	K_{i_rede}	α_{i_rede}	ξ
1.4744	1.0167×10^4	0.01	$2\sqrt{2}$

IV. SIMULATION RESULTS

Simulations are performed using Matlab Simulink toolbox in order to verify if the system operates according to the theoretical study previously elaborated. Initially, a simulation with a constant value of irradiance was performed: $G = 700 W / m^2$. In the second test the irradiance in the first 2 seconds is $G = 500 W / m^2$, increasing to $G = 800 W / m^2$ after 3 seconds of simulation.

In Test 1 it is verified that the system is working correctly, the current and voltage in the PV panel array are constant, as well as the voltage in the capacitor C_1 , as shown in figures 8, 9 and 11. The proportional controller, which has been sized to control this voltage, is working correctly, as well as the MPPT, guaranteeing that the current and the voltage do not oscillate abruptly.

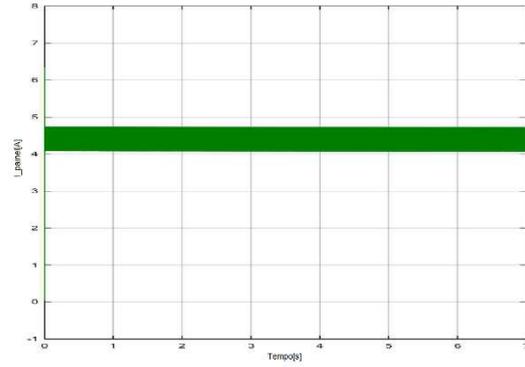


Fig. 8 - Current on the PV panel

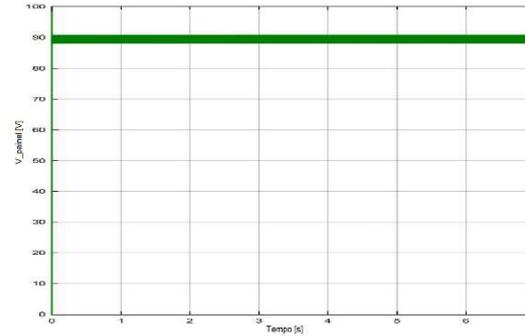


Fig. 9 - Voltage in the PV panel

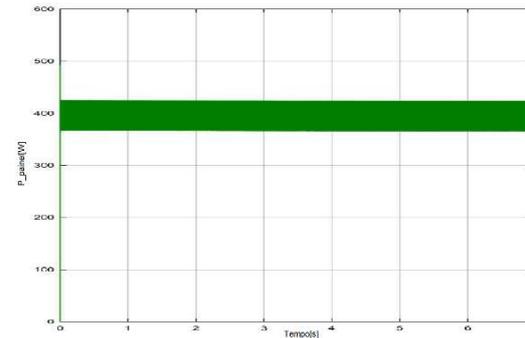


Fig. 10 - Power in the PV panel

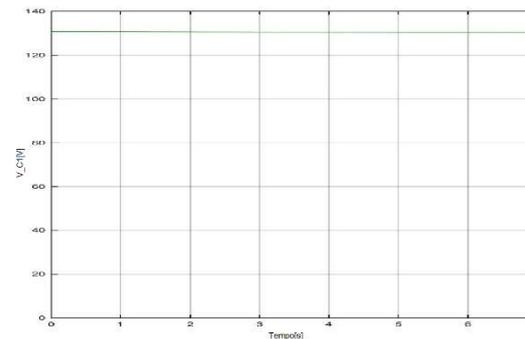


Fig. 11 - Voltage in capacitor C_1

In figure 12 it is observed that the voltage in the primary of the high-frequency transformer corresponds to the previously sized value of 130V for the primary voltage of the high-frequency transformer and of 450V for the voltage in the secondary, to ensure that the grid connected inverter that works correctly.

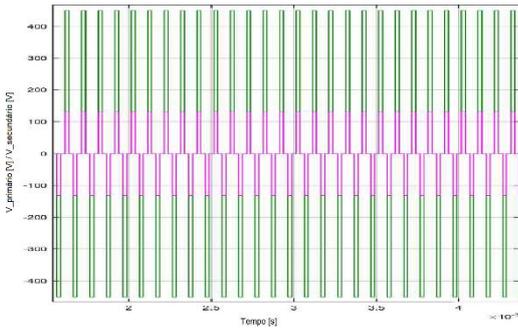


Fig. 12 - Primary voltage (pink) / Secondary voltage (green)

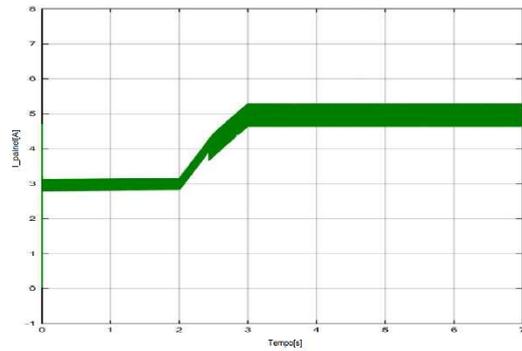


Fig. 15 - Current in the PV panel

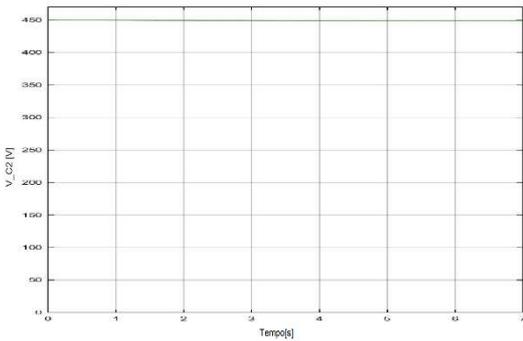


Fig. 13 - Voltage in capacitor C_2

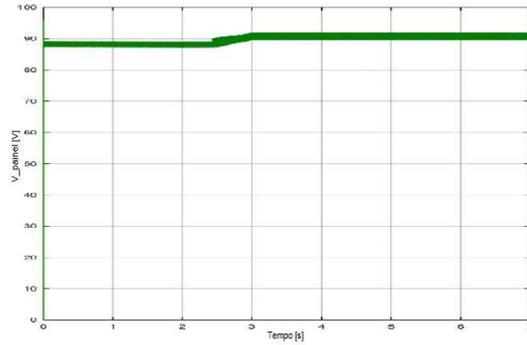


Fig. 16 - Voltage in the PV panel

Figure 14 shows the grid voltage and current zoomed in to see that they are both in phase.

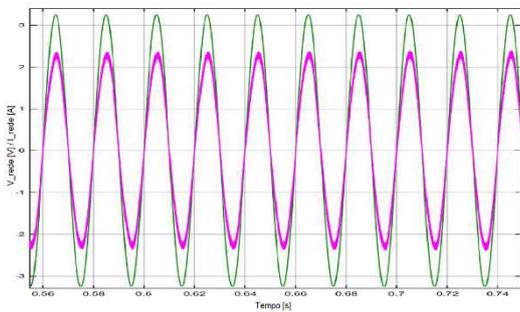


Fig. 14 - Grid voltage (green) / grid current (pink)

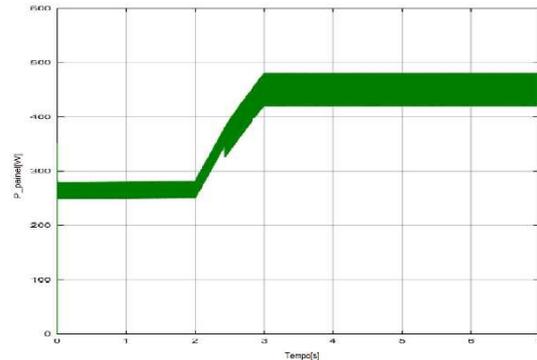


Fig. 17 - Power in the PV panel

Test 2: $G = 500 \text{ W} / \text{m}^2 \rightarrow G = 800 \text{ W} / \text{m}^2$

In Test 2, when the irradiance increases, an increase in the value of the current and voltage in the photovoltaic panel is observed. The voltage in the capacitor remains constant, as shown in figures 15, 16 and 18. Thus, it is known that the proportional controller, which has been sized to control this voltage, and the MPPT, are working correctly, since they do not let the current and the voltage oscillate abruptly, ensuring that the capacitor C_1 is always charged, with a practically constant voltage value.

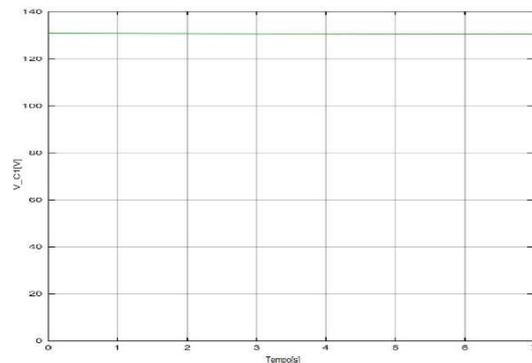


Fig. 18 - Voltage in Capacitor C_1

In figure 19, for a better visualization and comparison of the mains voltage and the current injected by the microgeneration system, the mains voltage was multiplied by a gain of 0.01. In these conditions, it is verified that the grid voltage presents the value of

approximately 325V, which corresponds to the amplitude of the voltage in the network.

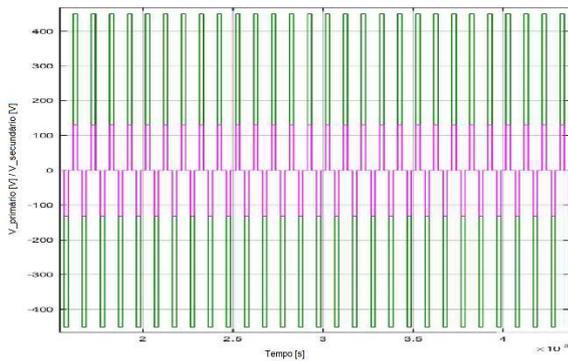


Fig. 19 – High frequency transformer primary voltage (pink) / secondary voltage (green)

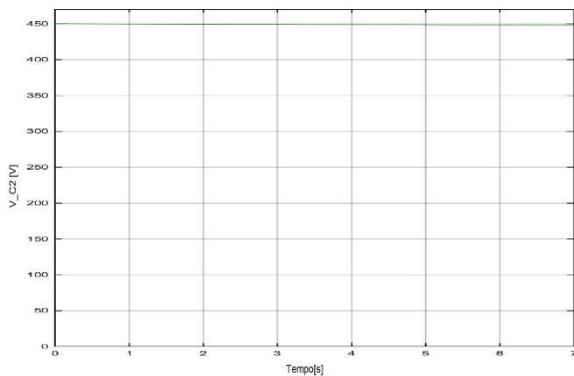


Fig. 20 - Voltage in capacitor C₂

For a better visualization and comparison of the mains voltage and current injected by the microgeneration system, in figure 21, the mains voltage was multiplied by a gain of 0.01. In these conditions, it can be seen that the mains voltage presents the value of approximately 325V, which corresponds to the amplitude of the voltage in the network.

For the test carried out, the current will increase its value, as the irradiance increases.

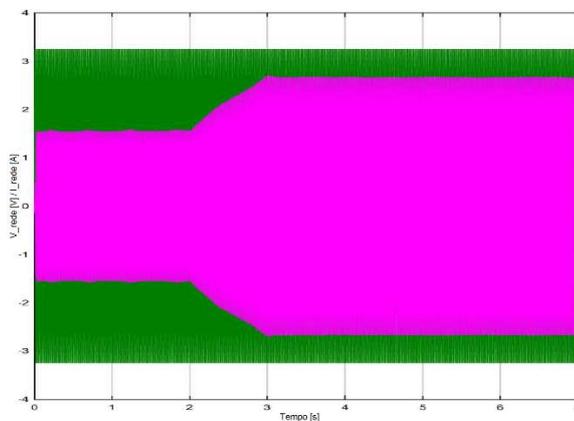


Fig. 21 - Grid voltage (green) / grid current (pink)

Figure 22 shows a detail of figure 21 to show that the current is in phase with the voltage.

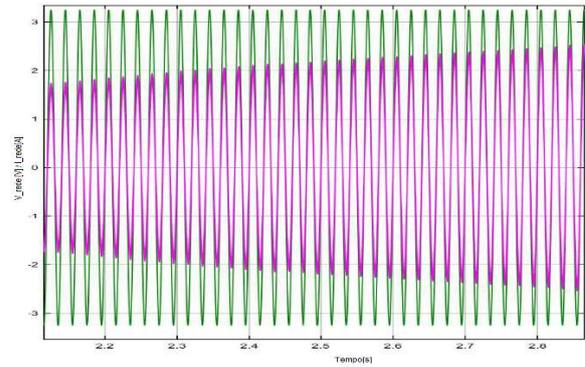


Fig. 22 – Grid voltage network (green) / Grid current (pink)

V. CONCLUSIONS

The proposed system consists of a photovoltaic panel which, through a DC-DC converter, allows the maximum power (MPPT), and increases the output voltage, guaranteeing a nearly constant value.

The proposed system was simulated in the Matlab program, using the Simulink toolbox. The obtained results allow us to conclude that it works correctly, since MPPT and the stability of the current and voltage value of the panel are guaranteed, and there are no fast oscillations. In addition, the voltage control of the capacitor C1, and the voltage value on the primary side of the high-frequency transformer, is ensured.

The voltage in the transformer secondary is always higher than 400 V, thus ensuring that the inverter connected to the grid works correctly, with sinusoidal current and almost unitary power factor.

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