

Study and Production of a Two-Stage DC/DC DC/AC Converter for Generating an Alternating Voltage from a Direct Voltage Supplied by a Photovoltaic Array

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Abstract

This article presents an ongoing study of the design of a DC-AC inverter using a single renewable energy source. The proposed approach makes it possible to produce an output with an H-bridge or full bridge and a single energy source. To this end, the performance of the inverter was studied first by means of a simulation and then with the implementation of an experimental device.

Keywords

Inverter, DC-AC Converter, Performance

1. Introduction

The main types of energy used on an industrial scale are: electrochemical conversion; photoelectric conversion; thermoelectric conversion and electromechanical conversion.

Most of these processes are reversible, in the sense that it is possible to restore electrical energy from the initial form of energy. Electrical components of varying complexity, used in electrical circuits, have been specially designed to perform this type of conversion.

In the remainder of this work, we will focus on the conversion of radiant energy, solar energy or photovoltaic energy into electrical energy. To do this, a power device is needed to perform the conversion. This conversion chain will consist of two stages. The first stage is a DC-DC converter consisting of a quadratic-type

boost and the second stage is a converter with a full-bridge or H-bridge structure [1].

This dissertation, which is one of a series, is devoted to studying the performance of the second DC/AC stage. This study will be carried out in two stages. Firstly, modelling followed by simulation using MATLAB/Simulink software. Then we will move on to practical validation.

2. Modelling the DC-AC Converter

The role of the device is to generate an AC voltage from a DC voltage. This is done in a fairly complex way, *i.e.* there is an increase and conversion of the fixed DC voltage to a variable DC voltage before the nature of the voltage changes from DC to AC in the second stage, as shown in **Figure 1**.

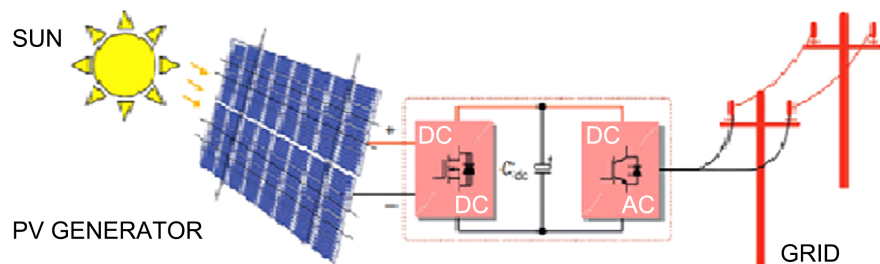


Figure 1. Typical components of a grid-connected photovoltaic inverter system.

A DC-AC converter is a static converter that converts electrical energy from direct current (DC) to alternating current (AC). In fact, this energy conversion is achieved by means of a control device (semiconductors). It is used to obtain an AC voltage at the receiver terminals that is adjustable in frequency and RMS value, using an appropriate control sequence as shown in **Figure 2** [2].

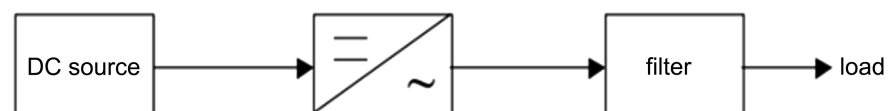


Figure 2. Continuous/alternative conversion chain.

Because of their configuration, DC-AC converters can be divided into two categories: half-bridge converters and full-bridge converters.

2.1. Half-Bridge Converters

This is the simplest configuration, as shown in **Figure 3**, using a single switching cell with two complementary switches [3].

The diodes are placed in parallel with the transistors. Their role is to ensure current continuity. This is because an inductive load cannot withstand a sudden interruption in current. So, after Q_1 has blocked, the I_{ch} current continues to flow through the D_2 diode, which conducts spontaneously.

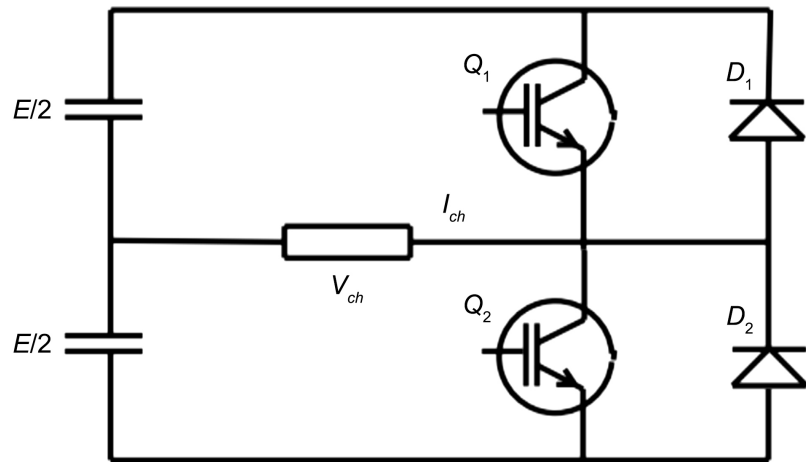


Figure 3. Structure of a half-bridge DC/AC converter.

When transistor Q_1 conducts, the load sees a voltage $V_{ch} = E/2$. The current I_{ch} grows exponentially according to a time constant.

When transistor Q_1 is blocked, diode D_2 starts conducting to ensure current continuity. The load then sees a voltage $V_{ch} = E/2$. The current I_{ch} then decreases. When the current passes through 0, a control signal is sent to the base of Q_2 . The D_2 diode blocks and the I_{ch} current continues to increase in the opposite direction. When Q_2 blocks, diode D_1 takes over and the load again sees a voltage $V_{ch} = E/2$.

When the current passes through 0, Q_1 is made to conduct and the cycle resumes.

When the current passes through 0, Q_1 is made to conduct and the cycle resumes.

Its structure is simple and economical, with only two controlled switches and two diodes, a single switch passing at each instant so reduced voltage drop.

Its main disadvantage is that the switch blocking voltage is twice the maximum voltage at the load terminals. In addition, the power can only be adjusted by pulse width modulation; the switching frequency is then 6 to 10 times that of the fundamental of the load.

2.2. Single-Phase Full-Bridge Inverters

The voltage-controlled inverter configuration shown in **Figure 4** consists of a stable DC bus, full-bridge switches, an LC low-pass filter and a resistive load R representing the power consumers. Unipolar SPWM (sinusoidal pulse width modulation) signals are generated by the controller and applied to drive the full bridge switches.

Mathematically, this DC-AC inverter can be modelled as a second-order system.

Given that the voltage across the inductor is given by the relation:

$$V_L = L \frac{di_L}{dt} \quad (1)$$

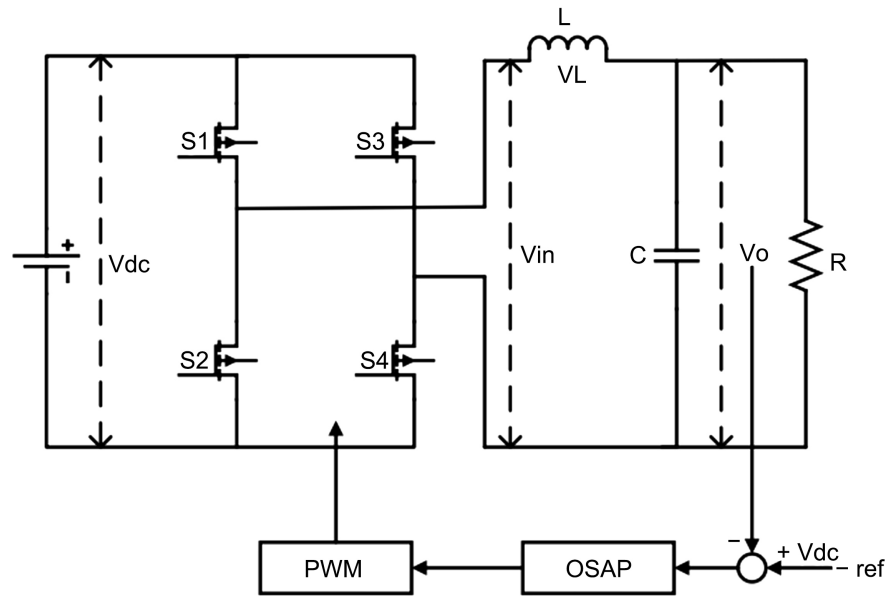


Figure 4. Structure of a full-bridge DC/AC converter and regulation.

In steady state, the output voltage V_{in} can be expressed as follows:

Since the voltage V_{in} is equal to $V_L + V_o$, we can write

$$V_o = L \frac{d\left(\frac{V_o}{R} + C \frac{dV_o}{dt}\right)}{dt} + V_o \quad (2)$$

$$LC \frac{d^2 V_o}{dt^2} + \frac{L}{R} \frac{dV_o}{dt} + V_o = V_{in} \quad (3)$$

On the basis of Equation (3), a representation of the state space of this dynamic system can be obtained using a function in the form of a state vector

$$\begin{bmatrix} \dot{V}_o \\ \dots \\ \ddot{V}_o \end{bmatrix} \quad (4)$$

So the equation describing the complete bridge is:

$$\begin{bmatrix} \dot{V}_o \\ \dots \\ \ddot{V}_o \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{1}{CR} \end{bmatrix} \begin{bmatrix} V_o \\ \dot{V}_o \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{LC} \end{bmatrix} V_{in} \quad (5)$$

As mentioned previously, single-pole SPWM signals are applied to control this inverter. According to the control scheme, the switches of each branch of the full-bridge inverter are switched separately. Four combinations of switch activation states and corresponding voltage levels are expected as follows:

- | | | | |
|-------------------|------|-----|----------------------|
| 1) S_1 et S_3 | sont | ON: | $V_{in} = 0$; |
| 2) S_1 et S_4 | sont | ON: | $V_{in} = +V_{dc}$; |
| 3) S_2 et S_3 | sont | ON: | $V_{in} = -V_{dc}$; |
| 4) S_2 et S_4 | sont | ON: | $V_{in} = 0$; |

The input voltage pulse is represented in the equation and this three-valued switched voltage V_{in} can be expressed as follows [4]:

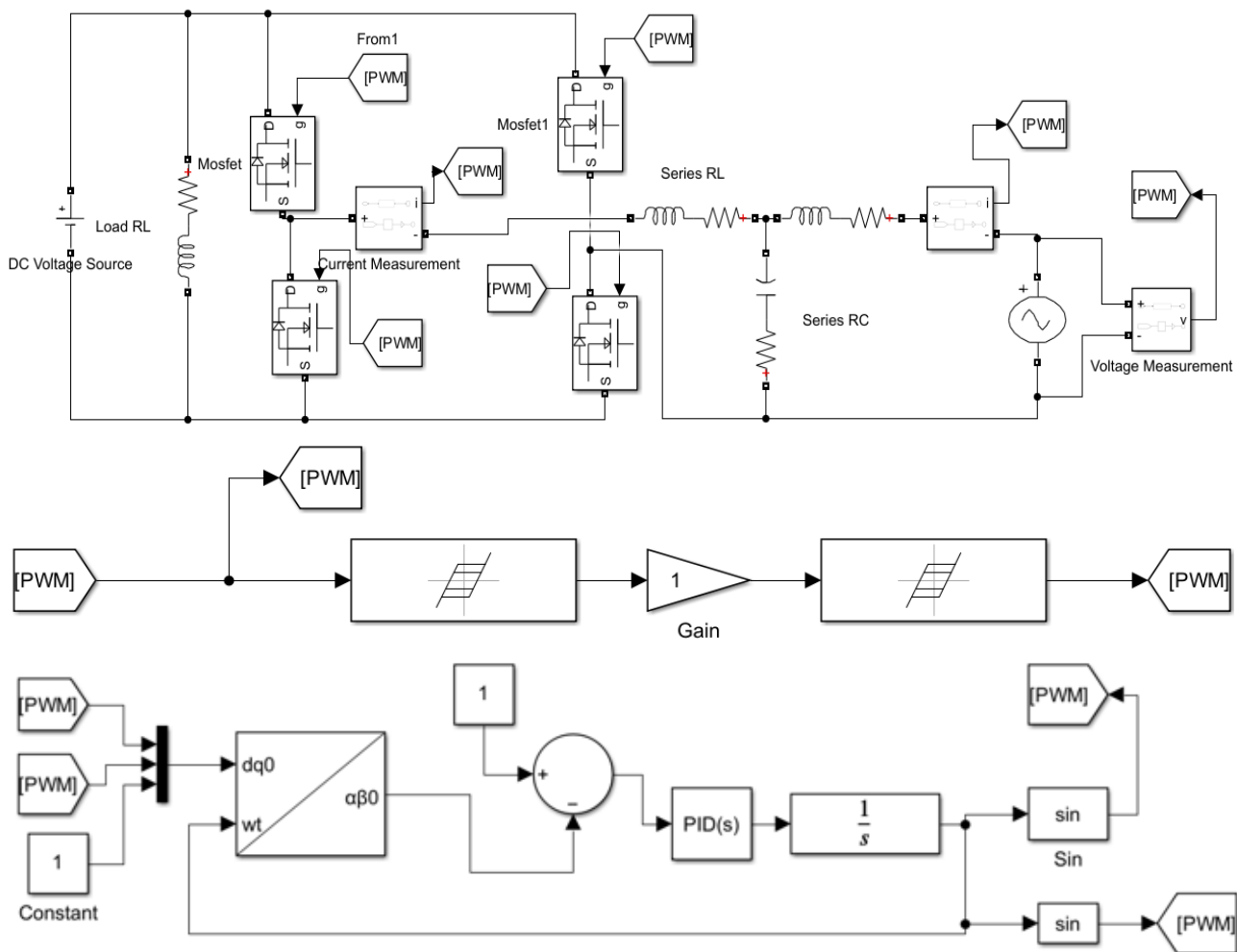
$$V_{in} = \begin{cases} \pm V_{dc} & \text{insides of perid } \Delta T \\ 0 & \text{outside the period } \Delta T \end{cases} \quad (6)$$

3. The Complete Diagram of a Device

Still using Matlab/Simulink software, we are going to represent the complete structure of the two-stage regulator plus an implementation of the regulation. As shown in the diagram below, **Figure 5** is represented in block form.

The first block contains the DC-DC converter connected to the DC-AC converter plus the LCL filter. Note that the DC-AC converter is an H-bridge controlled by a PWM signal at the MOSFETs. A PR control communicates with the PWM signal and the PLL takes care of the external control.

The output signal of the full bridge voltage is not sinusoidal and has harmonic distortions. These harmonics can be eliminated by using filters. Several filters exist in the literature, so we will present some of them before choosing the most suitable filter for the H-bridge [5].



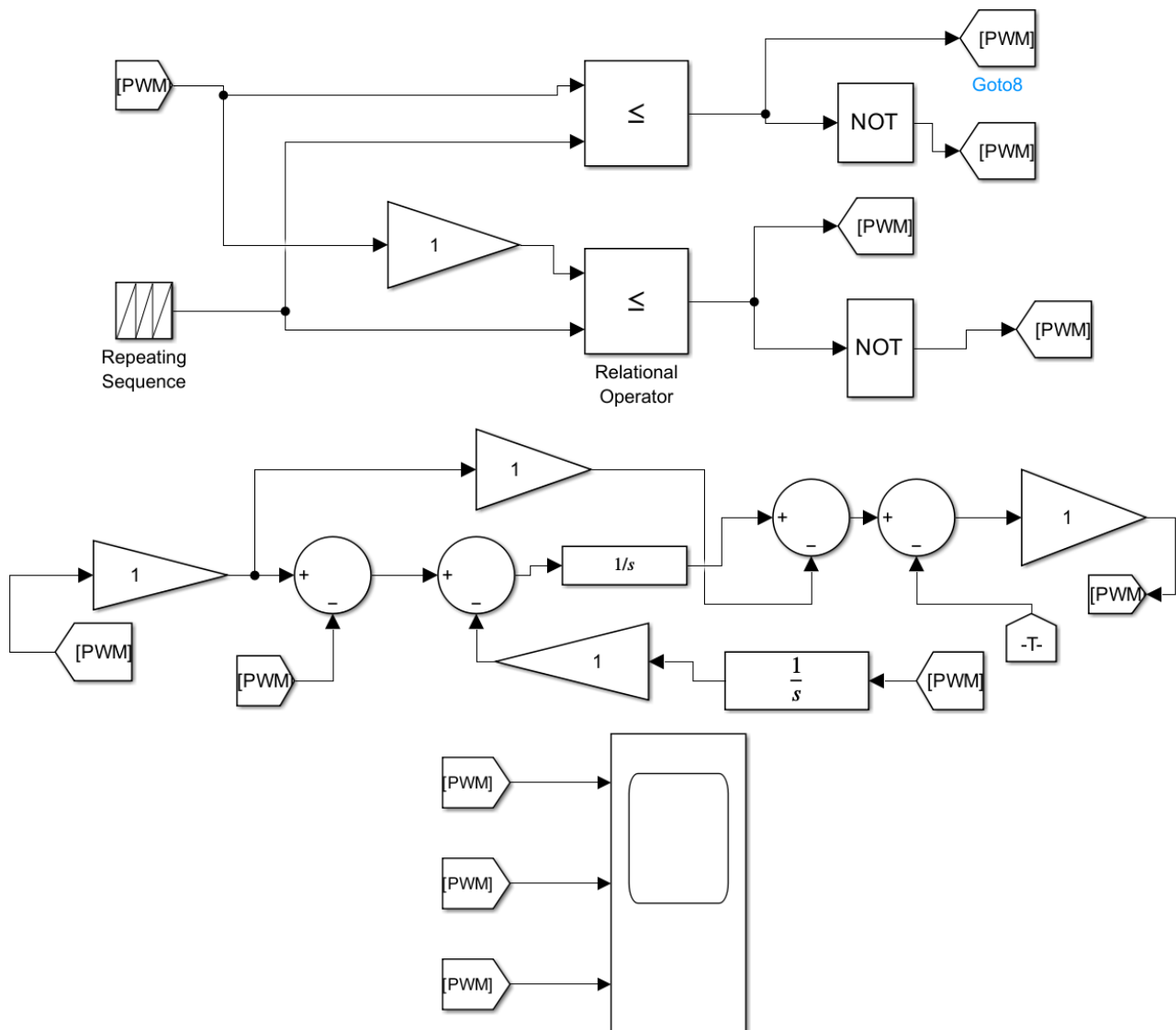


Figure 5. Simulation of a single-phase H-bridge inverter.

A PLL, or phase-locked loop, is used for external control. This is a complex electronic circuit that allows the instantaneous output phase to be locked to the instantaneous input phase, and also an output frequency to be locked to a multiple of the input frequency.

The basic principle of the three-phase or single-phase PLL is to apply an inverse Park transformation to the three-phase or single-phase network voltages. The q-axis component generated by this transformation is set to zero by adjusting the angle of the park reference frame in order to generate the synchronization angle [6].

The result of the simulation is shown in the following figure. The result obtained in **Figure 6** shows a sinusoidal curve. This curve reflects a variation from a fixed DC voltage to a variable AC voltage whose maximum value is greater than 300 V.

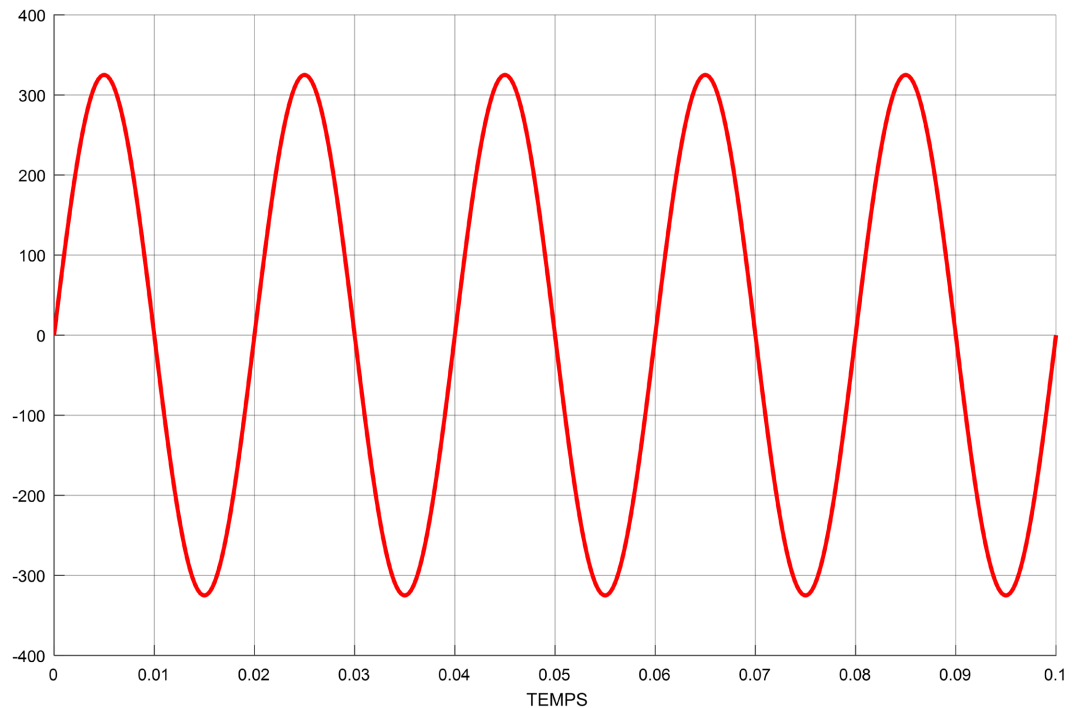


Figure 6. Result of the simulation.

SENELEC's mains or distribution network operates with a single-phase 220 V AC voltage. So even if there are losses, the output voltage will be sufficient to communicate with the network. We can therefore validate our simulation model.

4. Results

In this section, we present the experimental set-up, in particular the complete synoptic diagram of the conversion chain, and then go on to show the different types of signals obtained. **Figure 7** shows the diagram of the experimental device, i.e. the different parts that make up the DC/AC converter. This source feeds a quadratic DC-DC converter which, from the 17 V source, makes it possible to obtain a DC voltage of around 300 V.

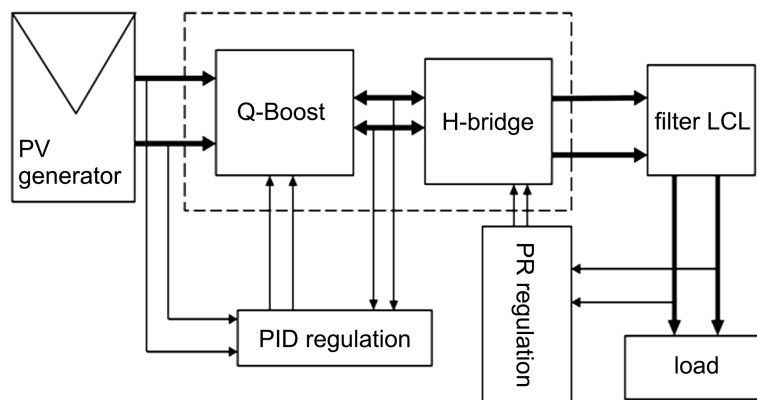


Figure 7. Diagram of the experimental set-up.

5. Discussion

At the beginning we have a PV generator delivering a DC voltage of about 17 V, this voltage must first be increased by a quadratic type boost quadratic converter to a voltage of 300 V. Then the bridge part H will take care of its conversion into alternating voltage AC.

The conversion chain proposed in this work is designed to operate from a CS-SP140 photovoltaic module with a voltage of 17V at the maximum power point. In order to carry out our experiments under all circumstances, we used a stabilized power supply as the PV module [7].

The 300 V supplies the complete bridge with its 4 power Mosfets transistors. It is this bridge that produces the rectangular output voltage that drives the LC low-pass filter.

The converter control and the PID regulator are implemented in a Texas instrument MSP42 microcontroller.

This same microcontroller also controls the full bridge. The role of the microcontroller is to control the transistors in order to generate switching. The control signal for the Mosfet transistor of the DC-DC converter is of the PWM type at 60 kHz, whereas for the full bridge there are 4 types of signals:

- Two signals in phase opposition at 50 Hz to drive the lower transistors of the H bridge.
- Two complementary signals at 16 KHz to drive the transistors of bridge H. The images are given in **Figure 8**.

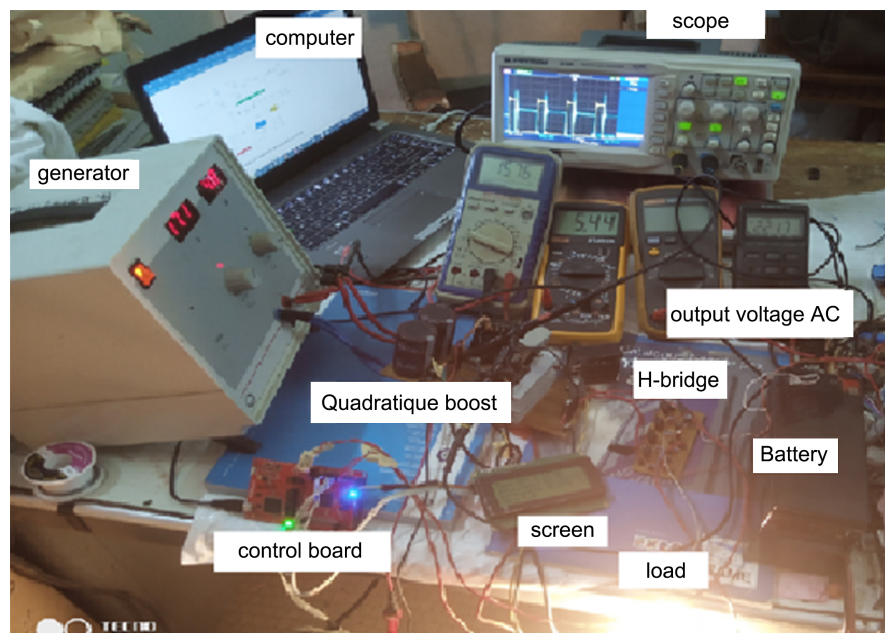


Figure 8. Illustrative photo of the experimental set-up.

We now show the configuration of the H-bridge control transistors in **Figure 9** below.

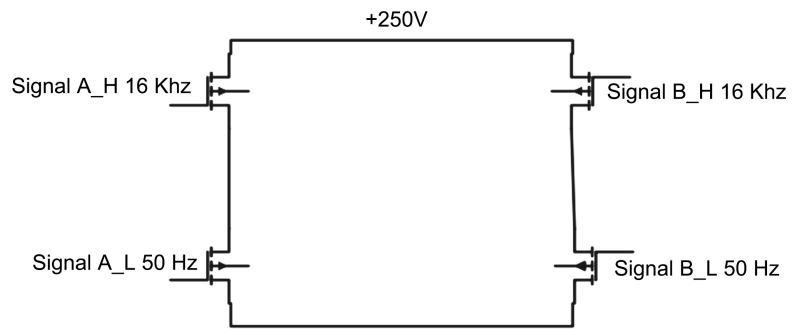


Figure 9. Control transistor configuration.

This involves displaying the control signal for the power transistor at the quadratic boost converter. The signal from the MSP432 microcontroller is 3.3 V; it drives a control circuit dedicated to the power transistor: the IR2110 requires a control signal of between 10 and 15 V. The signals obtained are shown in **Figure 10** below.



Figure 10. Waveforms of the A-L and B-L signals from the DC-AC converter.

This figure shows the signal from the MSP432 (blue signal) with an amplitude of 3.3 V and the signal from the IR2110 (yellow signal) with an amplitude of almost 15 V.

In this section we present the bridge control signals as mentioned in the synopsis, *i.e.* the A-L (blue) and B-L (yellow) signals in **Figure 11** and the A-H (blue) and B-H (yellow) signals in **Figure 11**.

The aim of this section is to study the variation in conversion efficiency under the effect of load and under the effect of input voltage. This will enable us to determine the efficiency of our system and its robustness.

In this section, we present in **Figure 12** the output voltage signals of the complete bridge without filtering and with filtering.

Without the filter, we obtain in **Figure 13** a symmetrical rectangular output signal where we can see the presence of the 16 kHz signals. It's this signal that needs to be filtered and to do this we've used an LC filter.

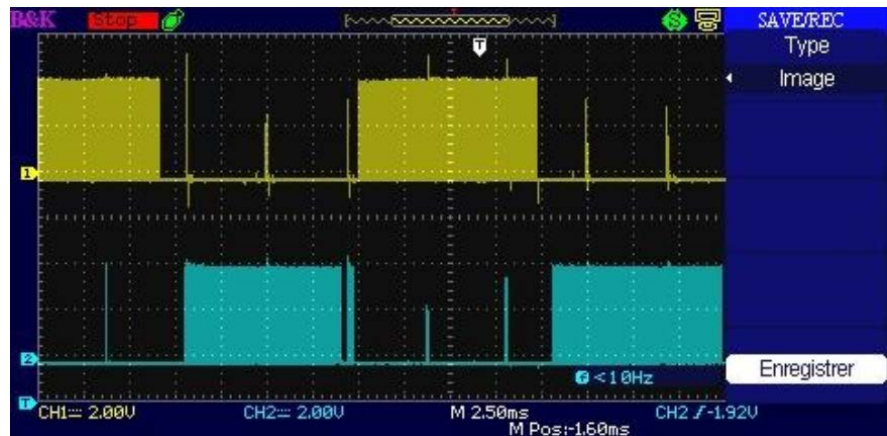


Figure 11. Waveforms of the A-H and B-H signals from the DC-AC converter.

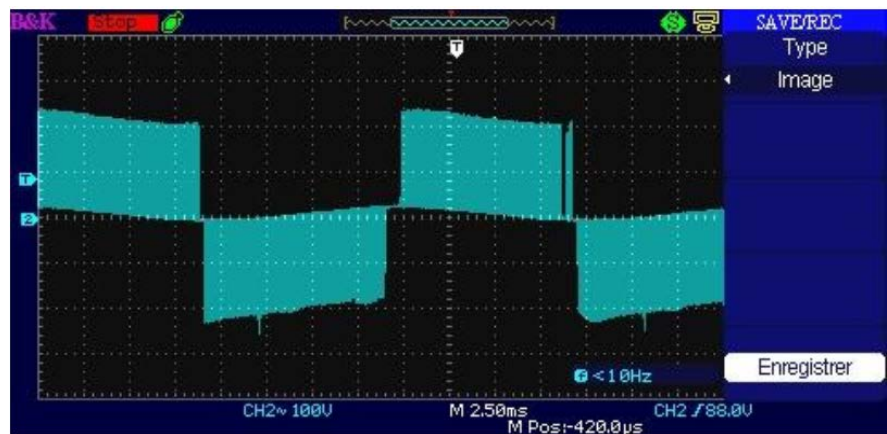


Figure 12. Output voltage without filter.

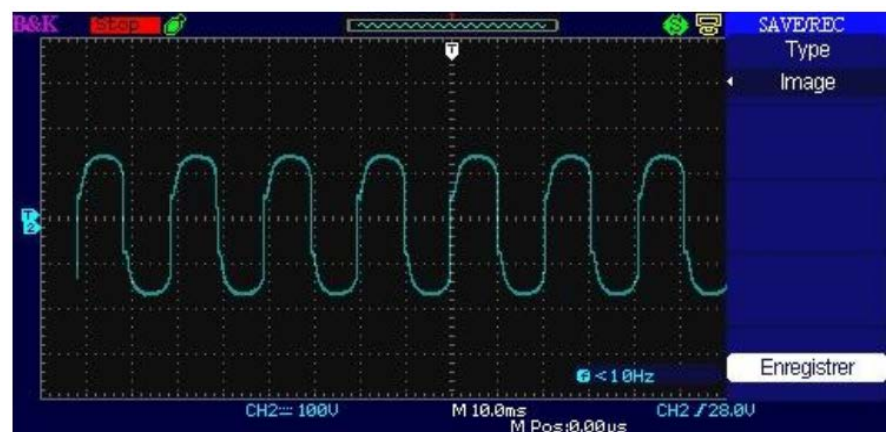


Figure 13. Output voltage with filter.

The presence of the filter has effectively improved the shape of the output voltage, but it is not perfectly sinusoidal. The core currently in use does not correspond to a suitable core. We plan to modify the signals at 16 kHz to achieve better filtering.

6. Conclusion

We have proposed a study of the performance of a DC/AC converter for a photovoltaic application. This converter is capable of generating a voltage that can be synchronized with that of the distribution network. However, for perfect conversion, induction of a PLL and suitable control are required.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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