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Energy produced by photovoltaic plants injected on the electric network

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- ✓ DC / DC converter,
- ✓ three-phase inverter,
- ✓ PWM control,
- ✓ MPPT control,
- ✓ Injection to the power grid
- ✓ Detection of the malfunction

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Abstract

In this article, the presented work concerns the photovoltaic energy, which stands out as a real solution to the future energy production: a very low-polluting and friendly production of the environment. The goal of this work is the design and modeling a photovoltaic (PV) system connected to the network of electrical distribution and transmission, equipped with the malfunction detection blocks. The studies have focused on the injection of a power of 16 kW, produced by a PV panel field on the medium voltage electrical network (25 KV). To the reliability of the injection system on the network and minimize power losses, we have inserted blocks that control the opening and closing of power switches of the DC / AC converter and synchronize the phase, the amplitude as well as the frequency of the voltage and the current injected on the power grid. The results show that the designed system detects the malfunction of the network side system (voltage dips, phase shedding, frequency fluctuation, unbalanced three-phase system), the field side of PV panel (distrust converters ...) and ensures the injection of electrical energy on the network during operation of the PV system.

1. Introduction

The energy produced by a photovoltaic plant requires no fuel. There is therefore no emission of greenhouse gases or polluting fumes [4,6]. Moreover, there is no waste from this energy production. As a result, the photovoltaic panel does not release polluting and toxic substances into soils, water reservoirs or the environment [1,3]. Today, thanks to its reliability and its eco-friendly concept, Photovoltaic's takes a prominent place.

The connection of PV Photovoltaic systems to the distribution network can have some impact on electrical networks: Impacts on the change of power flows, voltage level, protection plan, energy quality or network planning …. The characteristics, the operation and the disturbances on the distribution networks induce problems not yet solved which influence the operation of the PV systems [6,8,9]. This induces the failure of the blocks constituting the PV chain [15]: PV generator, DC / DC converter and inverter, control blocks (MPPT,...), ...

In this article, we analyzed each block constituting the PV System chain up to the electrical network such as cascade dual boost DC / DC converters and the inverter connected to the power grid.

2. Overall structure of the PV system connected to the electrical network

The structure of the PV system, connected to the electrical network, designed during this work is shown in figure1.The different blocks of this system are:

- PV generator
- Optimization block of the PV generator which is formed by a DC / DC converter and an MPPT control,
- DC / AC (three-phase inverter) converter controlled by a MLI control which provides a signal obtained by the comparison between a triangular signal and three signals obtained by the Park and PLL transform.The objective of this control is to control and synchronize the phase and the amplitude as well as the frequency of the voltage and the current injected on the electrical network,

- a malfunction detector which has the function of detecting any malfunctions in the chain and ensuring the production of the electrical energy optimized by the PV system,
- Transformer to isolate the photovoltaic system from the network, as well as the output voltage of the DC / AC converter to the desired level (depending on the network)
- Power grid (25 KV) to inject the energy produced by the PV system into the medium voltage power grid.

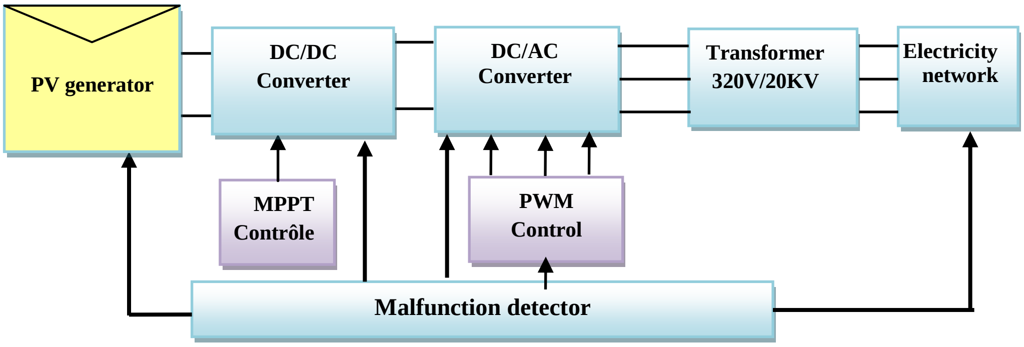


Figure 1: Synoptic diagram of the PV system designed, connected to the electrical network.

3. Functioning and discussion

3.1.*PV generator :*

In order to produce a photovoltaic power 16 kW, we used a photovoltaic panel field with a power of 60W. Typical current-voltage characteristics and power - voltage module array are shown in Figure 2-a, as a function of the illumination. It appears that under the standard conditions, illuminance of 1000W/m^2 and temperature of 25°C, the field of PV panels delivers a power of 16.78 KW, a current of 76.28A and a voltage of 220V (Fig 2). Otherwise, as shown in figure 3, the performance of a PV generator is strongly influenced by the temperature: an increase of 10 ° C. induces a degradation of 9%.

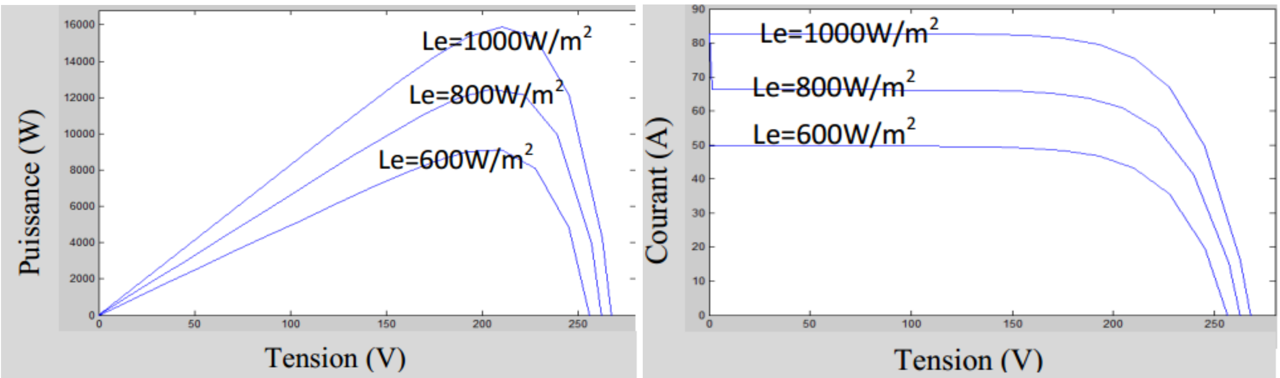


Figure 2: Electrical quantities P (V) and I (V) of the PV panel fields as a function of the illumination**.**

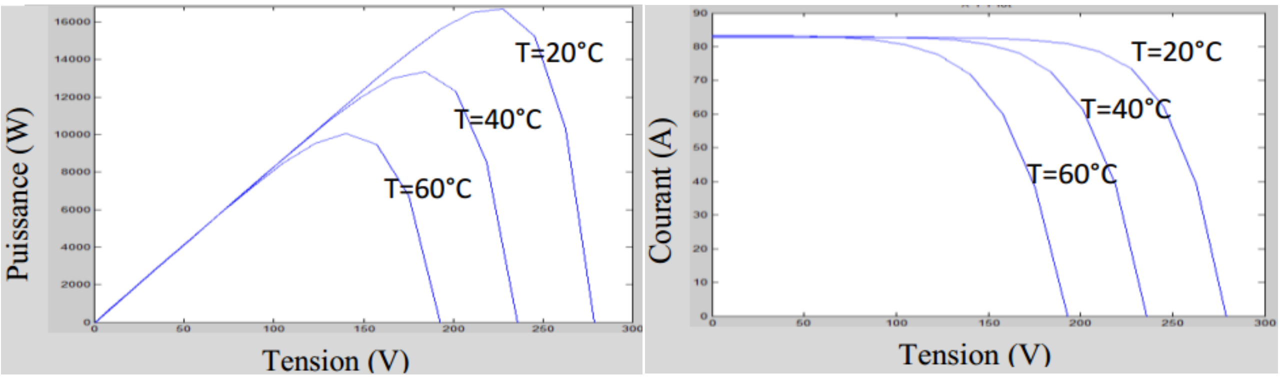


Figure 3: Electrical quantities P (V) and I (V) of the PV panel field as a function of temperature for 1000W / m^2 illumination.

3.2. *DC / DC Converters*

3.2.1 *Boost converter*

In order to extract at each instant the maximum power supplied by the field of panels, and to transfer it to the load and therefore to the electrical network, we used as a matching stage a boost DC / DC converter controlled by a Digital MPPT command. The role of the MPPT controller is to calculate and monitor the power, following an algorithm of Figure 4 based on the Hill-Climbing technical [16,17], the principle is to calculate the derivative of the power and to modify the duty ratio as a function of several parameters such as the derivation of the power at the end of the time delay and of the variable state used, in order to generate an optimal duty cycle which controls the DC / DC converter.

The typical electrical quantities obtained at the output of the Boost converter and the MPPT control is shown in figure 6. It appears that the duty cycle of the PWM signal (the order of 0.44) and the electrical quantities at the output of the converter = 16 kW, current = 28.40A, voltage = 565V) are consistent with the optimal ones (Figures 2 and 3).

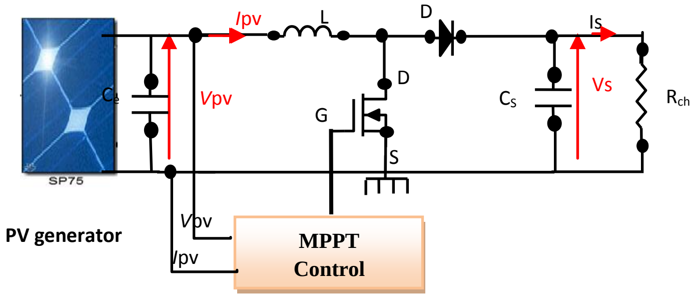


Figure 4: Structure of Boost Converter equipped with digital MPPT control.

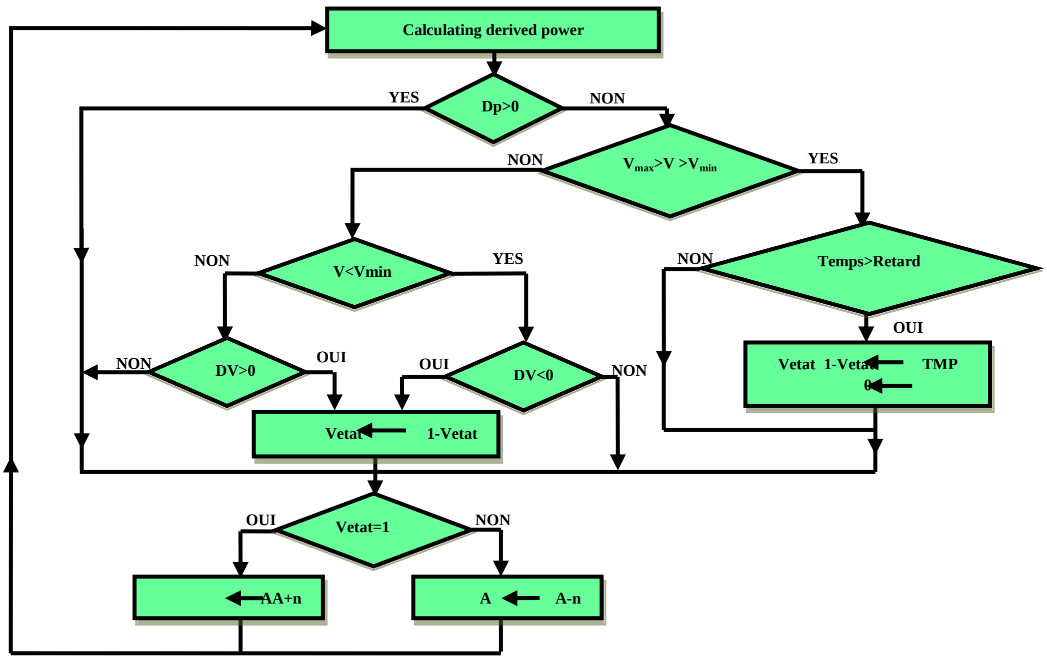


Figure 5: MPPT control algorithm (Hill-Climbing)

3.2.1 *Three-branch interlaced Boost converter*

In order to supply the inverter with a high, continuous voltage, we have inserted a DC / DC converter of the double boost cascade type, consisting of a three-branch interlaced boost converter connected in series with a boost converter controlled by the PWM control [16, 17], which aims to increase the 24 V voltage generated by two batteries in series up to 220 V at the DC / DC converter output (Figure 7).

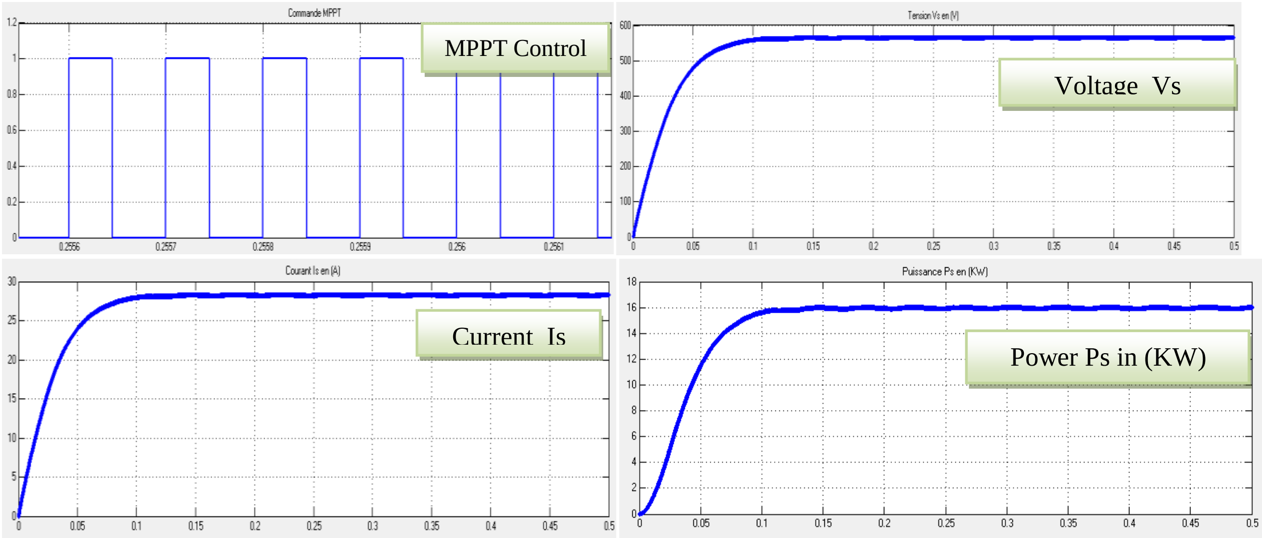


Figure 6: MPPT control, Electrical quantities of the Boost converter (voltage, current, power).

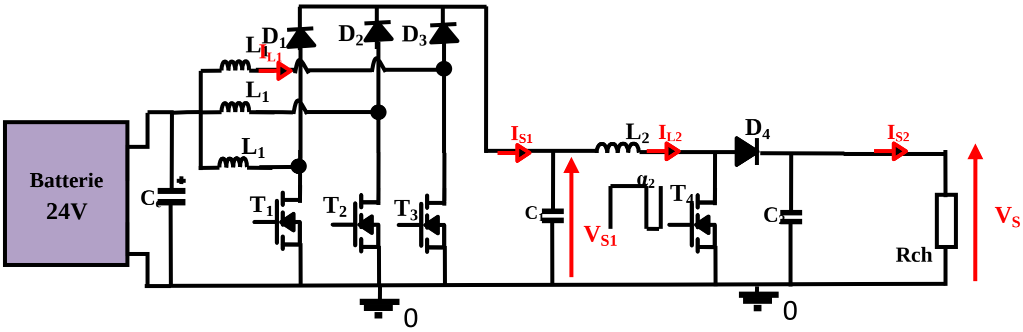


Figure 7: Diagram of the cascade boost converter

To study the DC / DC converter in a very profound way, we have shown in the figures below the variation of the electrical quantities (currents, voltages, output impedance) as a function of the variation of the load for the values of thus the variation of the voltages V_{S1} and V_S of the double cascade boost as a function of α_1 to a fixed α_2 value and the load R = 50 Ω, by representing below the different wave forms for a duty cycle α_2 fixed.

➢ **The electrical characteristics of a double cascade boost chopper for α1 = 0.5**

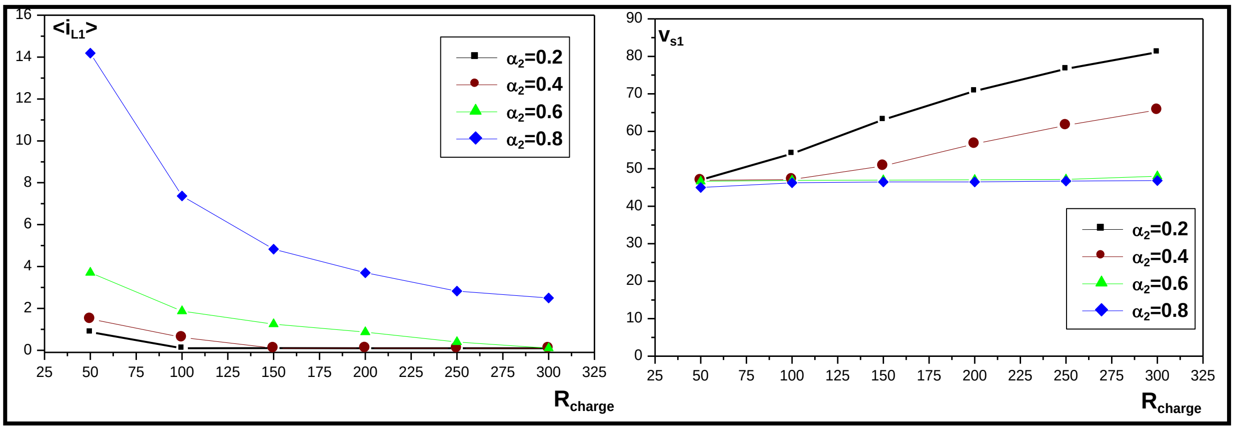


Figure 7: The variation of electrical quantities I_{L1} and V_{s1} according to the load to α_1 = 0.5

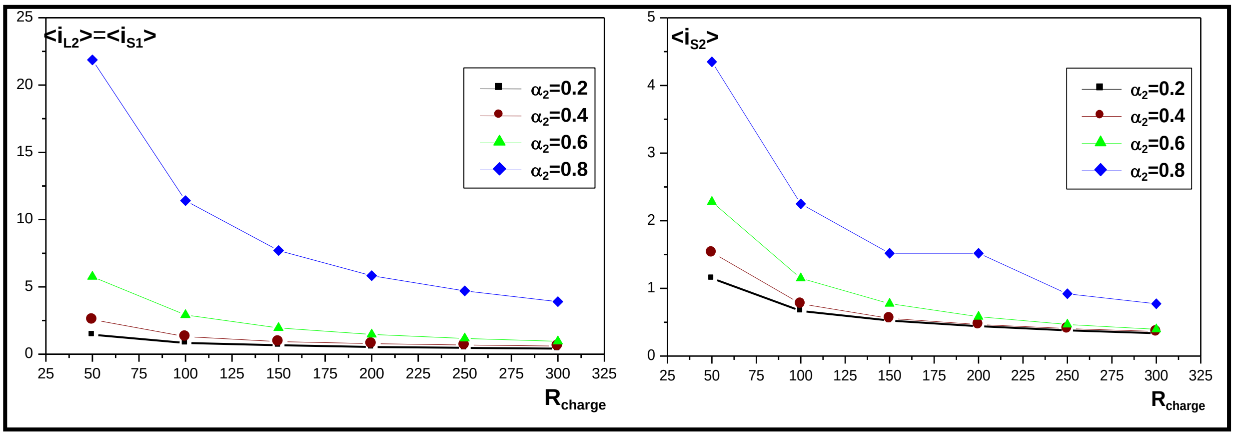


Figure 8: The variation of the currents I_{L2} and i_{s2} according to the load to α_1=0.5

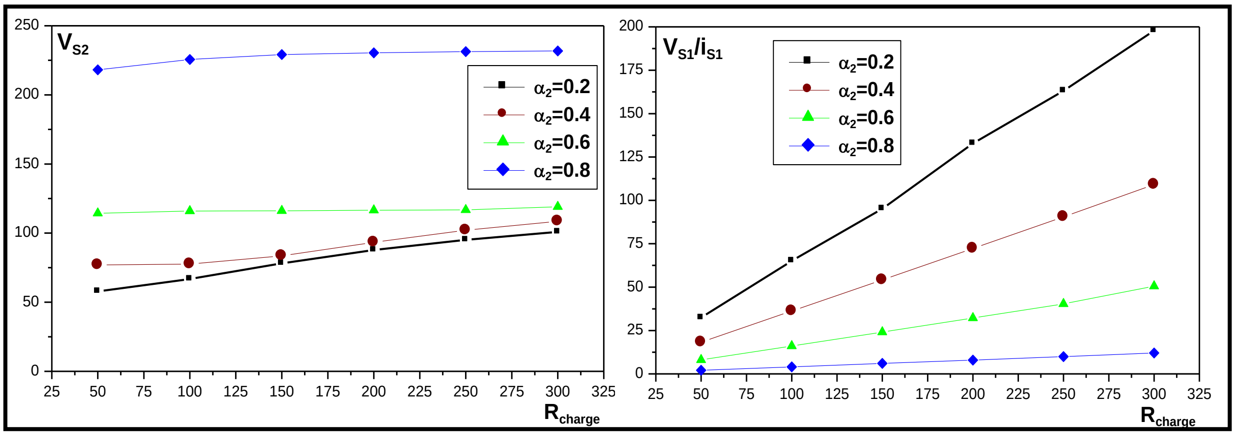


Figure 9: The variation of the voltage V_{S2} and V_{S1}/ i_{s1} impedance depending on the load $\alpha_1 = 0.5$.

- **The electrical characteristics of a double cascade boost at $\alpha_2 = 0.5$**

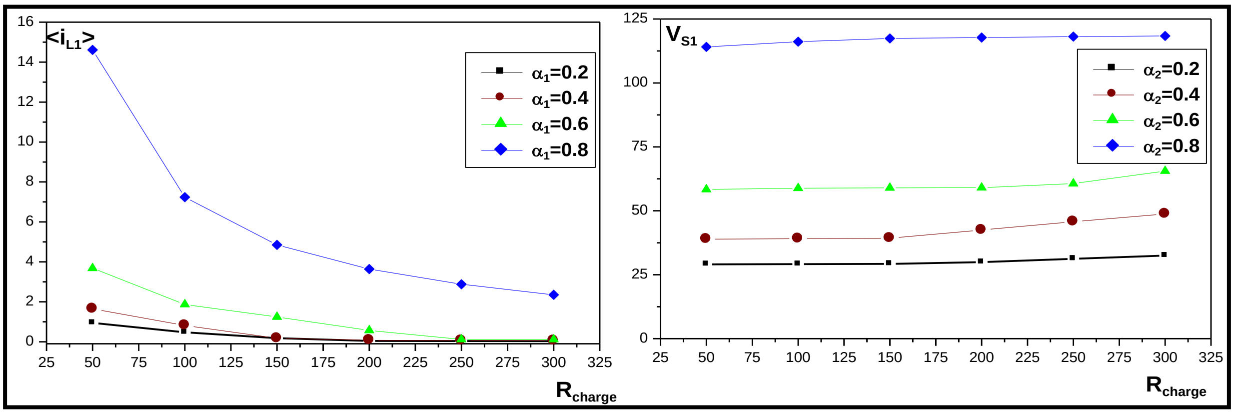


Figure 10: The variation of the currents i_{L1} and i_{s1} as a function of the load at $\alpha_2 = 0.5$

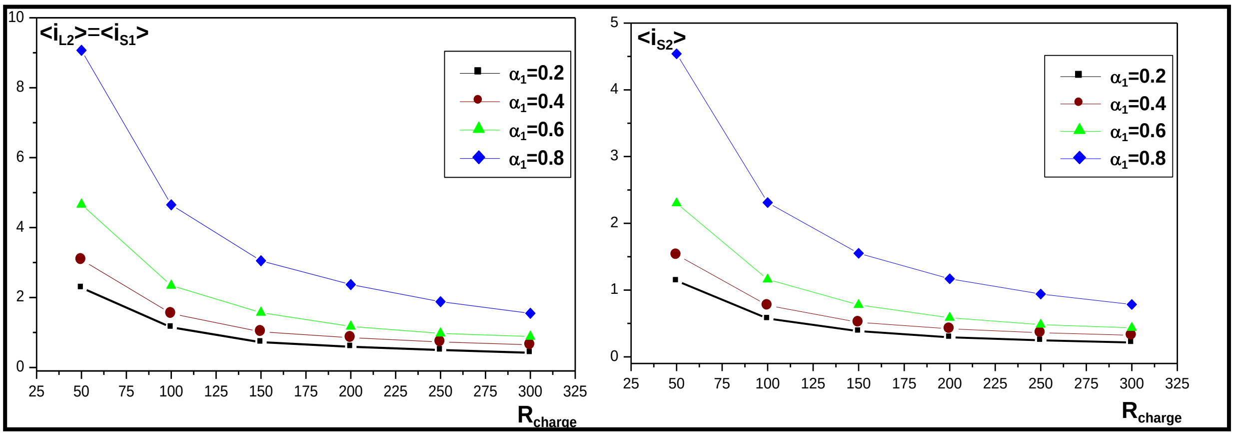


Figure 11: The variation of the electrical quantities V_{S1} and i_{s2} as a function of the load at $\alpha_2 = 0.5$

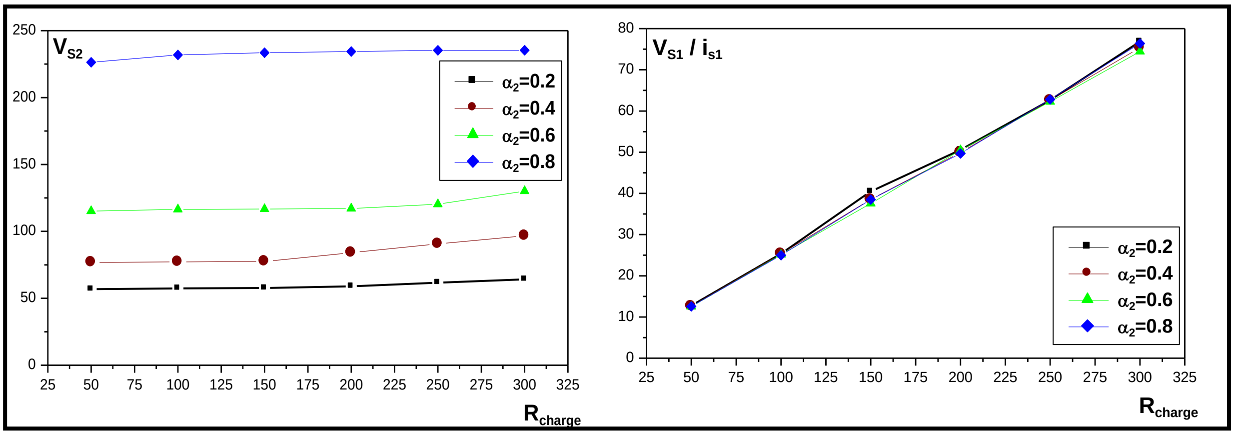


Figure 12: The variation of the voltage V_{S2} and V_{S1}/ i_{s1} impedance depending on the load $\alpha_2 = 0.5$

The following table summarizes the results obtained:

The electrical quantities	α_1**=0.5**	α_2**=0.5**
$<i_L>$	Decreases with increasing load and increases when the duty cycle when augment	
V_{S1}	Increase with the increase of the load by cons is decreases when α2 increases	It remains constant that the charge increases, and increases when α_1 increases
V_{s2}	Remains almost constant even as the load increases, and increases when the duty cycle increases	
V_{s1}/I_{s1}	Increases as R increases	Varies linearly with increasing load

Table 1: Summary of electrical characteristics of a double cascade boost

➢ **The variation of the voltages V_{S1} and V_{S2} as a function of α_2 to α_1 fixed**

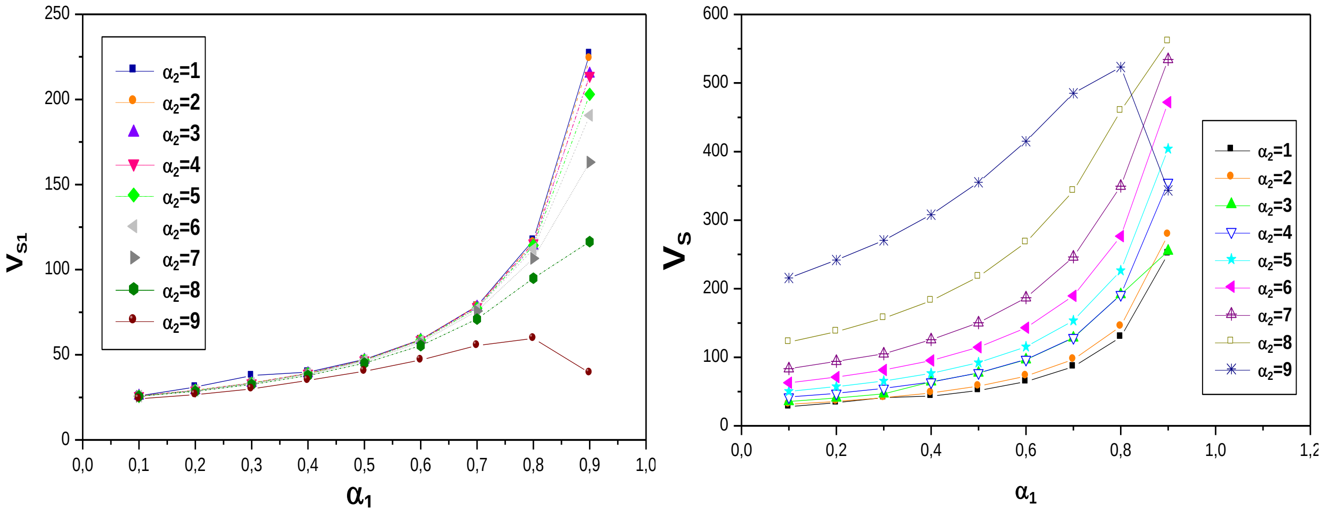


Figure 13: The variation of V_{S1} and V_S as a function of α_2:

From the simulation results obtained, it is noted that the currents <iL> of the first converter are of the order of 7.37 A, the voltage delivered by the DC / DC converter is the order of 225.61 V and the current of Order of 2.25A, then the power supplied by this converter is of order of 507.62W, with a yield 95.6%.

3.3. *DC / AC converter (Three-phase inverter)*

The switches of the three-phase DC/AC inverter (figure 14) are MOSFET transistors, equipped with freewheeling diodes, with voltages greater than 600V and current of the order of 60A.

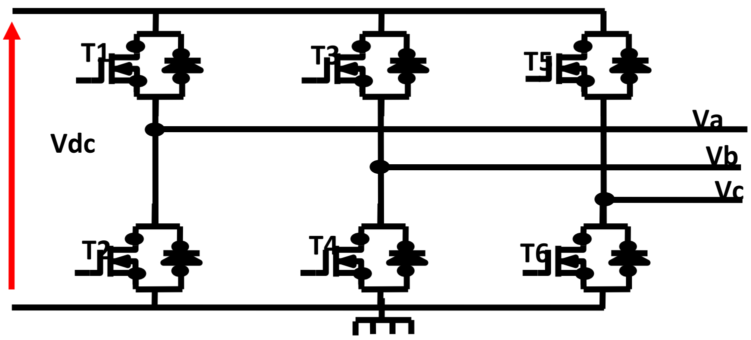


Figure 14: Circuit of three-phase inverter.

3.3.1 *System for protection and control of three-phase inverter switches.*

The power system uses a closed-loop control to regulate the power of the three-phase inverter. Power electronics systems, loads tend to have dynamic properties and power conditioning, the system equipment possesses dynamic properties like inductors and capacitors and some controllers introduce delays.The power converters behave as a non-linear impedance, which contains discontinuous nonlinear differential equations. These systems are still difficult to analyze although they have been simplified. For a regular three-phase voltage, the equation is given by:

$$\begin{cases} V_a = V_m \cos(w_e t) \\ V_b = V_m \cos\left(w_e t - {}^{2\pi}/_{3}\right) \\ V_c = V_m \cos(w_e t + {}^{2\pi}/_{3}) \end{cases} \quad \text{(eq.1)}$$

The equation (eq.1) clearly indicates the three-phase voltages are out of phase by 120 degrees of delay for each phase. In order to organize this non-stationary system in a fixed system, the transformation of the three simple DC component phase systems is necessary. To achieve this objective, three phase voltages can be seen as three voltage vectors that are rotating in three-dimensional space [14].

The transformation function used in this paper is Park Transformation (equation 2) and its inverse transform (equation 3), given by:

$$\begin{cases} V_a=V_d \sin(wt)+V_q \cos(wt)+V_0 \\ V_b=V_d \sin\left(wt-\frac{2\pi}{3}\right)+V_q \cos\left(wt-\frac{2\pi}{3}\right)+V_0 \\ V_c=V_d \sin\left(wt+\frac{2\pi}{3}\right)+V_q \cos\left(wt+\frac{2\pi}{3}\right)+V_0 \end{cases} \text{eq(2)}$$

$$\begin{cases} V_d=\frac{2}{3}\left[V_a \sin(wt)+V_b \sin\left(wt+\frac{2\pi}{3}\right)+V_c \sin\left(wt+\frac{2\pi}{3}\right)\right] \\ V_q=\frac{2}{3}\left[V_a \cos(wt)+V_b \cos\left(wt-\frac{2\pi}{3}\right)+V_c \cos\left(wt-\frac{2\pi}{3}\right)\right] \\ V_0=\frac{1}{3}(V_a+V_b+V_c) \end{cases} \text{eq(3)}$$

The various simplifications carried out after analysis of the system enabled us to conclude that the set point currents at the output of the upstream control will be injected at the point of connection of the PV production. These currents are calculated by means of the power references and the voltage measurement at the connection point; these will be calculated in the Park repository according to Equations (4) and (5):

$$P=\frac{3}{2}\left(V_d \, . I_d+V_q \, . I_q\right) \text{eq(4)}$$

$$Q=\frac{3}{2}\left(V_q \, . I_d-V_d \, . I_q\right) \text{eq(5)}$$

From the latter equation, the following two equations (7) and (8) are deduced:

$$I_{dref}=\frac{2(P.V_d+Q.V_q)}{3({V_d}^2+{V_q}^2)} \text{eq(6)}$$

$$I_{qref}=\frac{2(P.V_q-Q.V_d)}{3({V_d}^2+{V_q}^2)} \text{eq(7)}$$

With:

- P and Q: are the reference powers of photovoltaic production.
- Vd and Vq: are the direct and quadratic components of the voltage, in the Park repository.
- Id and Iq: are the direct and quadratic components of the current produced by PV production on the network.

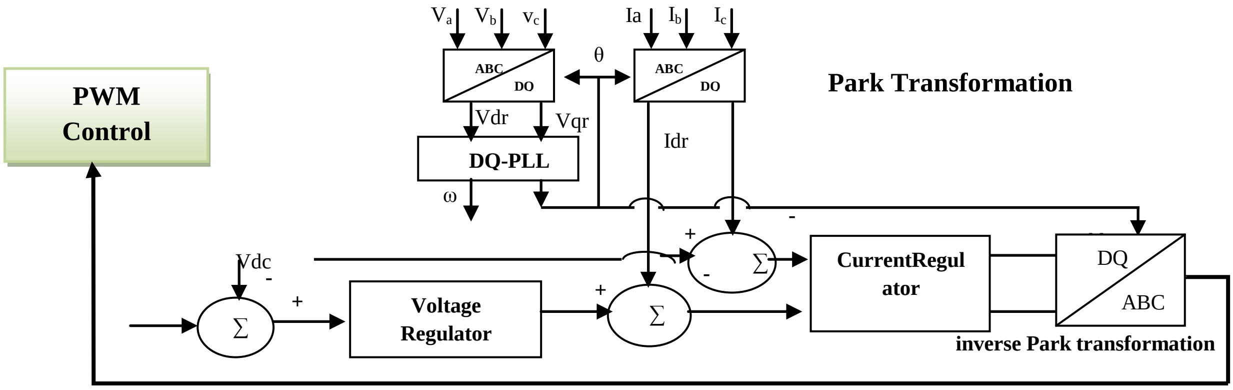


Figure 15: Structure of the protection system.

Figure 16 shows the voltage of the normalized amplitude network and the variation of the angle q, which varies from 0 to 2π. The results obtained show that at the beginning of the simulation, the signal obtained at the output of the PLL (sinθ, cosq) is ahead of the signal of the voltage of the electrical network, after some time the PLL seeks to render the two Signals in phase. Various disturbances can occur on the power grid (voltage dips, phase jump, harmonic, and imbalance…). The purpose of the PLL synchronization system is to reconstruct information on the direct component of the fundamental voltage and the PV system (Variation Of illumination, variation of temperature) the synchronization between the inputs signal and the output signal of the PLL is given in figure 15.

The characteristic of the voltages (Vdr, Vqr) of the three-phase voltages of the network (Vra, Vrb, Vrc) expressed by the PLL in the Park domain is given in figure 17.

The results of the simulation obtained from our control and control system show that the system is synchronized for a short time (in the order of 0.08s), then the PLL block ensures the synchronization of the control with respect to l The evolution of electrical network voltages.

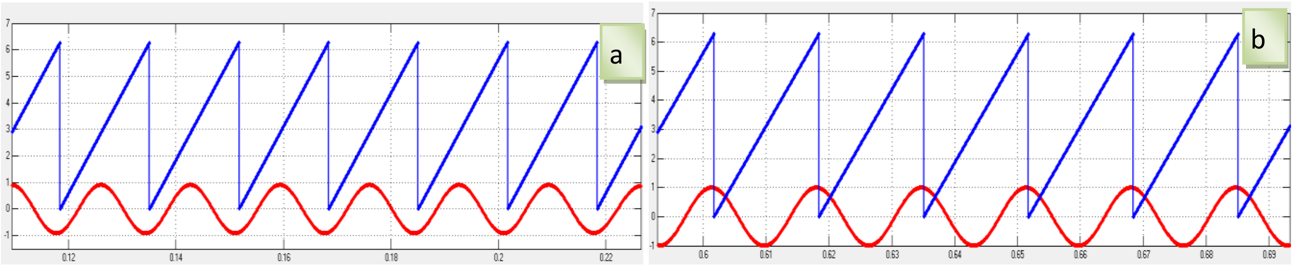


Figure 16: a- Synchronization at start of simulation.
b- Synchronization after some time of the simulation.

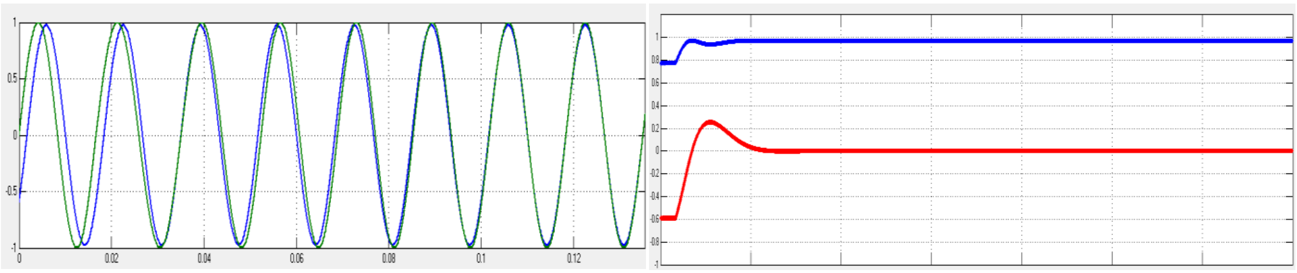
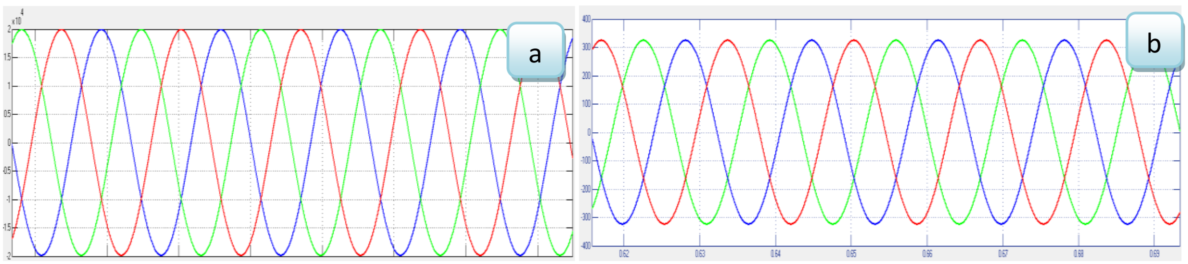


Figure 16: a- Synchronization between the input signal and the output signal of the PLL.
b- Characteristics of the voltages (Vdr, Vqr) expressed in the Park domain.

3.3.2. *Overall operation of the PV system connected to the grid:*

The voltage inverter connected to the mains is specified mainly by a voltage and current injected into the distribution network produced by a PV panel field [11].

The typical results of the electrical quantities obtained at the output of the inverter such as the voltages of the three arms of the inverter are purely sinusoidal, with an effective amplitude of 220 V offset by 2π and a frequency of 60 Hz (figure. 17-b), While the shape of the voltage obtained after the transformer is shown in figure 17-a.



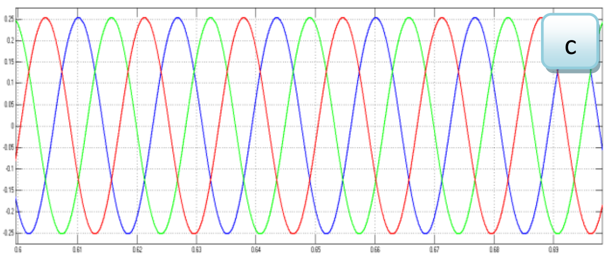


Figure 17: Form of the electrical quantities obtained at the output of the inverter as well as the electrical network voltage at medium voltage.
a- Power supply voltage
b- The voltage at the output of the inverter
c- The current injected into the power grid

The influence of the various perturbations mentioned above on the system realized, such as amplitude variation, frequency and phase, figures. 17, 18, 19, show that the protection and control system (Park Transform And

PLL) made it possible to regulate and manage the various parameters all while keeping their values that is to say, manages to synchronize the shape of the three-phase voltages and currents of the system and eliminate the disturbances in a very low time of order of 2 ms.

Moreover, we observed that when the amplitude of the disturbances is important, the system compares this amplitude with that of reference and eliminates the disturbed signal amplitude (figure. 18).

We also simulated the case of unbalance of frequency on the signals of the electrical network and we noticed that the phase locked loop regulated the unbalanced frequency (figure 19). In addition, in the case of presence of phase shift in the electrical network signals (Figure 20), the PLL system has to control and regulate the phase angle and jumps inflicted with a very short time.

When triggering the PV Panel field, or one of the converter power switches, the shape of the voltage and current signals supplied to the user are not influenced by the presence of the transformer.

According to the results obtained after the creation of the disturbances on the electrical network, we find that the synchronization system aims to reconstruct the information on the direct component of the fundamental voltage after the comparison of the currents and the disturbed voltages with its references. Our control system makes the system stable in a very short time.

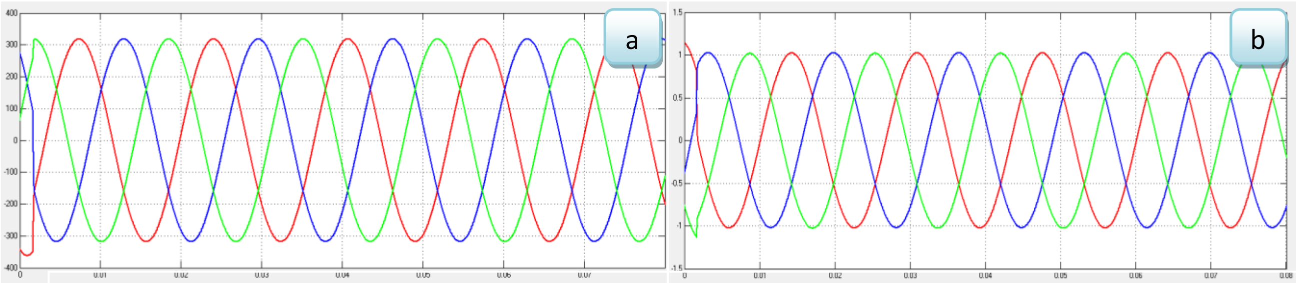


Figure 18: The shape of the electrical quantities obtained at the output of the inverter when disrupts the amplitude of the voltage of the electrical network.

a- The voltage at the inverter output
b- The current injected into the power grid

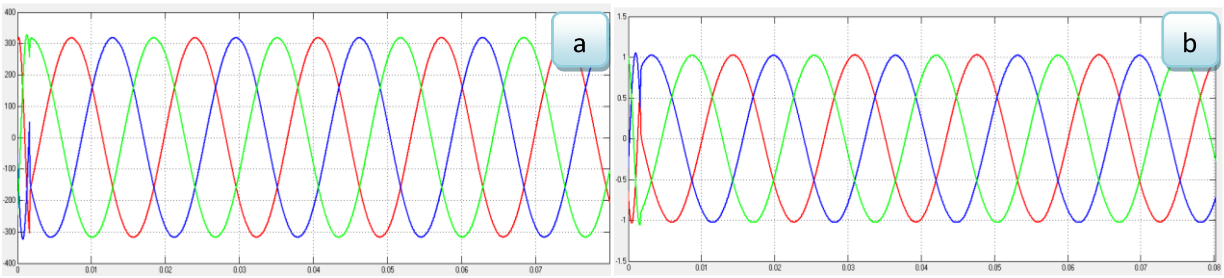


Figure 19: The form of the electrical quantities obtained at the output of the inverter after the change in the frequency of the electrical network.

a- The voltage at the inverter output
b- The current injected into the power grid

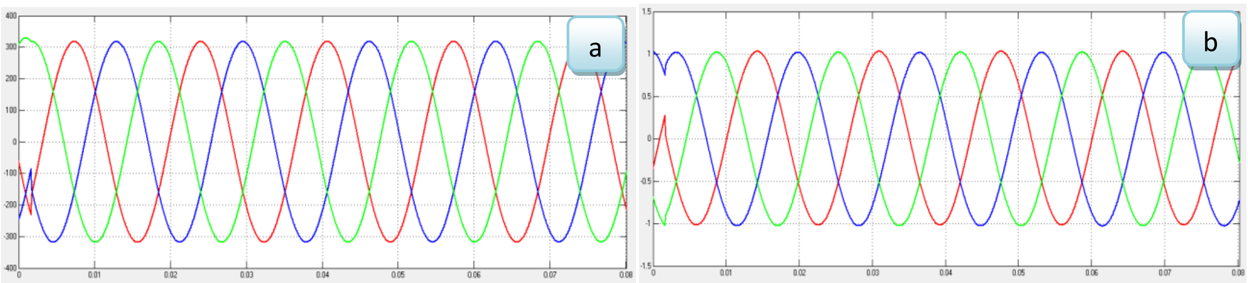


Figure 20: The form of the electrical quantities obtained at the output of the inverter after the phase jump on the electrical network.

a- The voltage at the inverter output
b- The current injected into the power grid

Conclusion

In this article, we presented the results of the simulation of a PV system connected to the network provided with the malfunction detection blocks. The overallresults show That : structure du Boost entrelacée est une solution efficace pour augmenter le niveau de puissance, car elle permet le partage du courant entre les phases.

- ✓ The waveform, the voltage and the current of the disturbances (amplitude, frequency, phase ...) is synchronized.
- ✓ The proposed method is faster and more accurate.
- ✓ The operation of the designed photovoltaic system that provides the network, regardless of disturbances (purely sinusoidal, efficiently and frequency 220V 60 Hz).

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