# Simulation of DC/DC Converter based on an Integrated Boost-C´uk Topology

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**Abstract:** ***A new non-isolated DC-DC converter for photovoltaic systems is proposed in this paper. This converter topology is characterized by an integration of the classical Boost and Cuk DC-DC converters. The proposed topology requires only a single power semiconductor switch, reduces voltage stress across diodes and power semiconductor switch while providing a continuous input current. Further, this topology allows extending the voltage static gain when compared with the conventional Boost converter. The new converter is regulated by a PWM technique at constant frequency that can be associated to a maximum power point tracking algorithm. Herein, the design considerations of this power converter are presented, and the characteristics of the proposed topology are confirmed by simulations and experiment results from a laboratory prototype.***

**Keywords:** boost, CUK, high step up converter, simulation

## 1. Introduction

Nowadays, consumption of electricity is increasing day by day and hence its demand is increased. Power generation by conventional energy sources such as oil and coal results in production of greenhouse gases such as $CO_2$, $N_2$, etc. which creates pollution and these sources are limited in nature. These problems make the researchers to work on renewable energy sources such as photovoltaic system because of its several advantages such as absence of noise, longer life, less time of installation, absence of pollution and noise, high mobility and portability of parts, simplicity and output power capability to reach load requirements. PV based grid connected and standalone system are fast developing in recent days all over world [1]. Main disadvantage of photovoltaic systems is their low conversion efficiency which makes it expensive technology. So researchers are working on this field to improve efficiency. In PV System algorithms of maximum power tracking are used to increase energy harvesting which results increase of efficiency. The design of PV cell for study is considered as $P_{MPP}$ =100W and $V_{MPP}$ = 15 volts and to increase the performance of system high step up DC-DC converters are used to convert the low voltage into high voltage as required for application. In grid connected system input of DC-AC inverter must be $\sqrt{3}$ times of grid voltage needed, so DC-DC converters are used to convert PV low voltage level to high voltage level which is needed. Renewable energy plays a fundamental role in the actual energy context Among the renewable sources, electricity generation from photovoltaic (PV) solar panels is growing rapidly despite the fact that PV panels have relatively low output voltage characteristics, regarding the load network needs. Therefore, many PV applications require a high step-up voltage gain and high efficiency DC-DC converter in order to increase and regulate the low PV DC voltage into a suitable utilization voltage. Besides the interconnection between the PV panels and the load, the DC-DC converter also performs the critical task of maximizing the photovoltaic system power output. In fact, the DC-DC converter, besides stepping-up the voltage is also controlled by a maximum power point tracking (MPPT) algorithm in order to continuously ensure that the PV panels are in their maximum power point (MPP) of their voltage-current electrical characteristics. In order to increase the output voltage of PV panels a simple step-up converter with high duty-cycle can be used. One of the classical DC-DC converters that can be used in this kind of applications is the boost converter  However, there is some limitation on the voltage gain, mainly due to parasitic elements associated to components such as inductors and power semiconductors. Moreover, there are some penalties due to high voltage stress across the power semiconductors. This will affect, for example Metal Oxide Semiconductor Field Effect Transistors MOSFET (or Insulated Gate Bipolar Transistors, IGBT) and diodes. Regarding diodes, when operated at high current and voltage levels their relatively high reverse recovery current originates switching losses that reduce the efficiency of the converter. One of the solutions to overcome this problem is to use a converter with a set-up transformer, such as the fly back converter. However, the use of a step-up transformer presents some problems like limitations in the operating frequency and the increase of problems associated of switching transients and leakage energy. Thus, new topologies in which the voltage gain is increased and the voltage stress across the power semiconductors is comparatively reduced had been proposed  in which several multiplier stages are used. Another class of topologies allowing high voltage gains is the quadratic converter. These topologies can be synthesized by cascading two converters in series while eliminating the redundant switches and controllers.

## 2. DC-DC Converter

The converter is used to convert DC voltage from one level to another level as needed on output. The main advantage of high step up converters is generation of high voltage at output which can be up to ten times of input voltage by using a single semiconductor switch. The boost converter is a conventional high step up converter which is used in high voltage applications. Boost converter is based on the step up principle which means output voltage will be always greater than the input voltage and its circuit model is as shown in fig 1. To improve the efficiency it is connected with both switched capacitor and coupled inductor. Boost converter is further upgraded to conventional interleaved boost converter for improving efficiency [3].

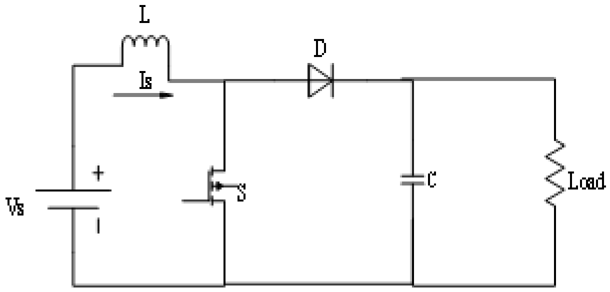


**Figure 1:** Boost converter

CUK converter, the conduction losses and switching losses are reduced, for smooth transition of current and voltage at output and input, switching techniques are provided. So due to CUK converter the conversion efficiency of PV system is improved and load meeting the dynamic energy requirement is done in efficient manner [4].

The advantages of CUK converter are-

- Power flows continuously via capacitor and this type of switch has minimum EMI radiation
- It has low voltage ripple on both the output and input sides of converter
- In CUK converter energy is transferred in bidirectional way by adding a diode and a switch

The circuit diagram of CUK converter is derived from duality principle of Buck-Boost converter as shown in fig3.The output of CUK converter has an inverted output. In this converter the output current passes through $C_o$. So $C_o$ is made with large electrolytic with low Equivalent Series Resistance and high ripple current rating for minimizing the losses.

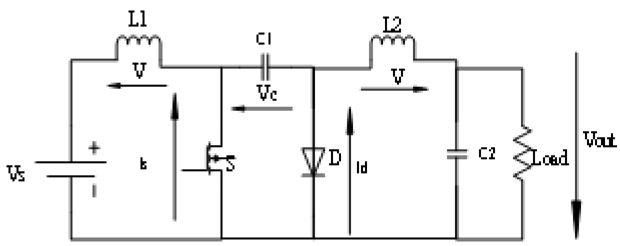


**Figure 2:** CUK converter

## 3. Operation of CUK Converter

Fig 5 shows the ON state operation of CUK converter, In this circuit when switch S is turned on current flows through inductor $L_1$ and MOSFET. It stores the energy in inductor $L_1$. As the switch is turned off, the voltage across inductor is reversed to maintain the current flow.

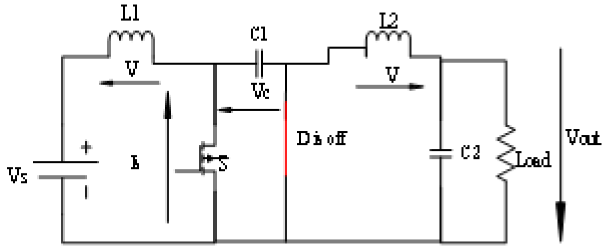


**Figure 3:** Mode 1 operation of CUK converter

In the off state period as shown in fig 6, current floes from input through inductor and diode, the capacitor $C_o$ is charged to a voltage which is higher than $V_i$ and transfer that energy to source. When MOSFET is turned on again capacitor completely discharge through inductor $L_2$ into load. Here $L_2$ and $C_o$ acts as a smoothing filter.

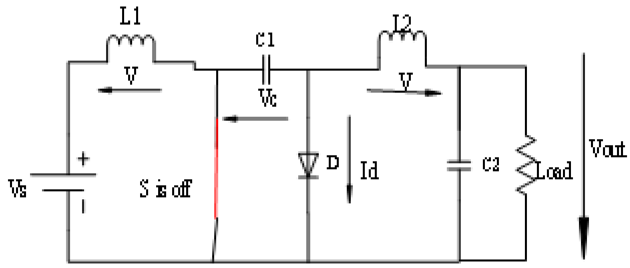


**Figure 4:** Mode 2 operation of CUK converter

### a) Continuous Conduction Mode

In continuous conduction mode of operation, at the beginning and at the end of the cycle, the energy stored in the inductor will be kept same. The energy stored is given by-

$$E = \frac{1}{2} L I^2 \tag{1}$$

This equation shows that the current through the inductors is kept same at the beginning and the end of the cycle. To satisfy the steady-state requirements, the average value of the inductor voltages over a commutation period is kept as zero. If the values of capacitors C and $C_o$ are designed with large values, the inductor voltages become higher [5]. The voltage across inductor is given by [6],

$$V_L = L \frac{di}{dt} \tag{2}$$

In the off state period of operation, inductor is connected in series with input voltage and capacitor so voltage across inductor can also be given as-

$$V_{L1} = V_i - V_c \tag{3}$$

Now, diode D is forward biased and inductor $L_2$ is directly connected to the capacitor. Therefore-

$$V_{L2} = V_o \tag{4}$$

In on state inductor $L_1$ is connected directly the input source, therefore-

$$V_{L1} = V_i \tag{5}$$

In the circuit diagram of CUK converter, the source side and load side components are separated by the capacitor. Due to this arrangement, energy transfer from the source side to



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load side occurs only through capacitor, which makes lesser ripple current at the source and load side.

**b) Discontinuous Conduction Mode**

The current will be discontinuous if the value of inductor is too small or below the critical inductance value [7]. The minimum inductance value is calculated by the formula-

$$L_{1\min} = \frac{1 - D^2 R}{2Df_s} \quad (6)$$

Where $f_s$ is switching frequency, D is duty cycle and R is load resistance

## 4. Integrated Boost-C´uk converter

The circuit diagrams of two classical DC-DC converters with voltage step-up characteristics are presented in Fig. 1. Fig. 1 circuit is related with the boost converter, while Fig. 2 represents the C´ uk converter. Both have been used alone in photovoltaic applications , despite their described voltage gain limitation. Analyzing these circuits it is possible to verify that both converters have similar parts, namely the boost inductor and the power MOSFET switch S in the input stage. Therefore, a hybrid Boost-C´ uk converter is proposed by merging their input stages, as can be seen by Fig. 5. This new converter is characterized by the use of a single switch S and an extended voltage static gain when compared with the classical Boost or C´ uk converters.[6]

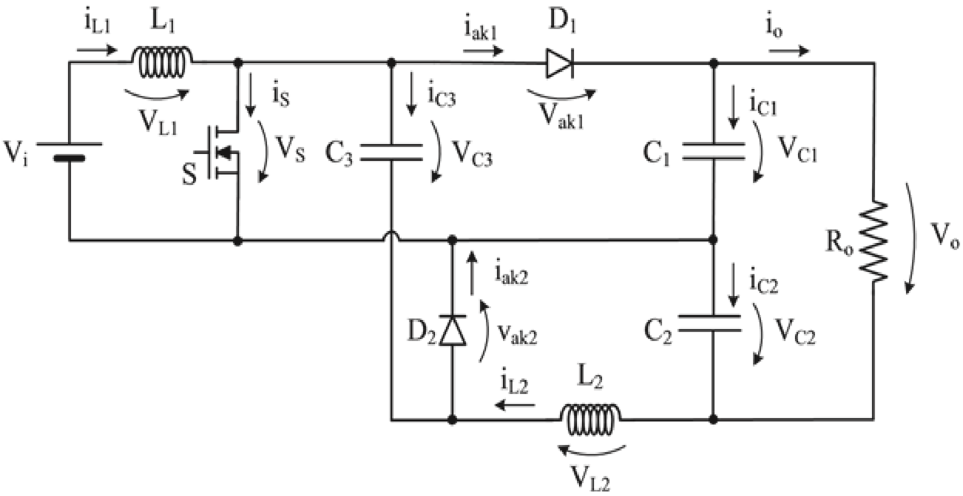



**Figure 5:** Proposed hybrid DC-DC converter with extended voltage ratio

Fig. 6 shows the voltage conversion ratio as a function of the duty-cycle d, for the converters presented in Fig. 1 and 2 and for the proposed hybrid converter in Fig. 5. It can be seen that the hybrid converter provides a substantial voltage gain, mainly for d > 0.5.[7]

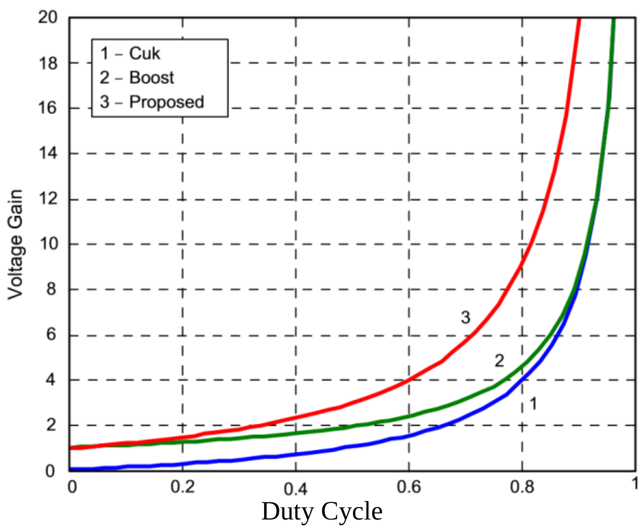



**Figure 6:** Static voltage conversion ratio as a function of duty-cycle.

**Table I:** Parameters of Boost and SEPIC Converter

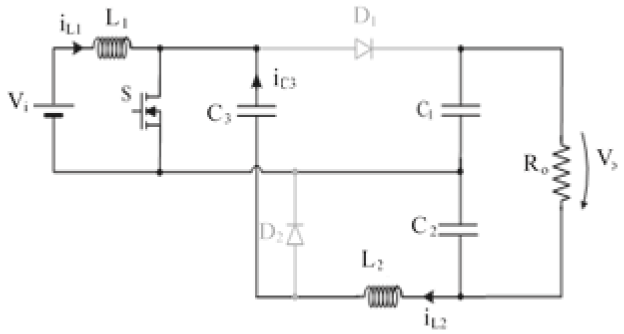
| Parameters | Boost Converter | CUK Converter |
|---|---|---|
| Duty Cycle | $D = 1 - \frac{V_{in}}{V_{out}}$ | $D = \frac{V_{out}}{V_{out} + V_{in}}$ |
| Inductance | $L_1 = \frac{V_{out} D}{\Delta i_L f}$ | $L_1 = \frac{V_{out} D}{\Delta i_{L1} f}$<br>$L_2 = \frac{V_{out} D}{\Delta i_{L2} f}$ |
| Capacitance | $C_o = \frac{D}{R(\Delta V_{out} / V_{in}) f}$ | $C_o = \frac{D}{R(\Delta V_{out} / V_{in}) f}$<br>$C_1 = \frac{D}{R(\Delta V_{C1} / V_{out}) f}$ |

The proposed hybrid topology Fig.5 is analyzed based on the assumption that the converter operates in continuous conduction mode and all components are ideal. According to this, the following three operating modes can described:

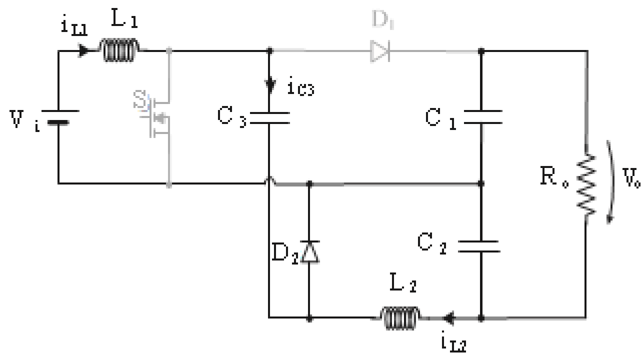
1) Operating mode A [$t_1$–$t_2$] Fig.6(a): This operating mode is effective when the power switch S is ON. The inductors $L_1$ and $L_2$ are in charging mode while capacitor $C_3$ is discharging. Diodes $D_1$ and $D_2$ are blocked respectively by the negative voltages $V_{C1}$ and $V_{C3}$.
2) Operating mode B [$t_2$–$t_3$] Fig.6(b): When the power switch S is turned OFF this operating mode can occurs if the voltage across the capacitor $C_3$ is smaller than the voltage across the capacitor $C_1$. During this period

capacitor $C_3$ will be charged (the voltage across this capacitor will increase) and the energy of inductors $L_1$ and $L_2$ is decreasing. Diode $D_1$ will stay blocked but diode $D_2$ will be ON.

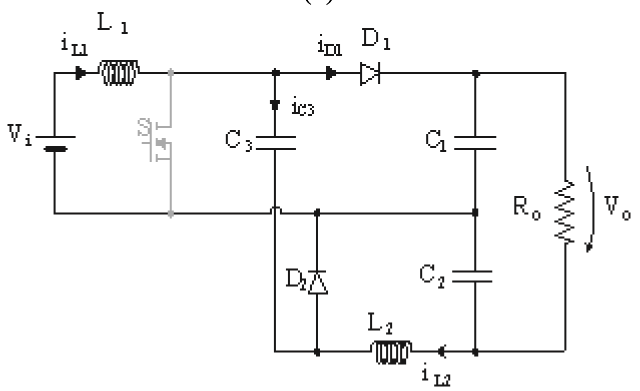
3) Operating mode C [$t_3$–$t_4$] Fig.7(c): This operating mode occurs when the power switch S is turned OFF and voltage across capacitor $C_1$ is equal or smaller than voltage across capacitor $C_3$. Both inductors are in discharging mode and capacitors $C_1$ and $C_3$ are being charged by the current that flows through the inductor $L_1$. Both diodes are turned ON.[8]




(a)




(b)




(c)

**Figure 7:** Converter operating modes

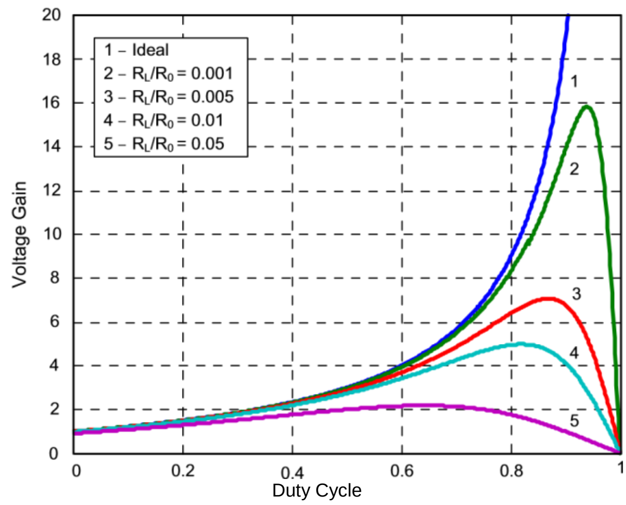



**Figure 8:** Static voltage conversion ratio as a function of duty cycle considering inductor losses

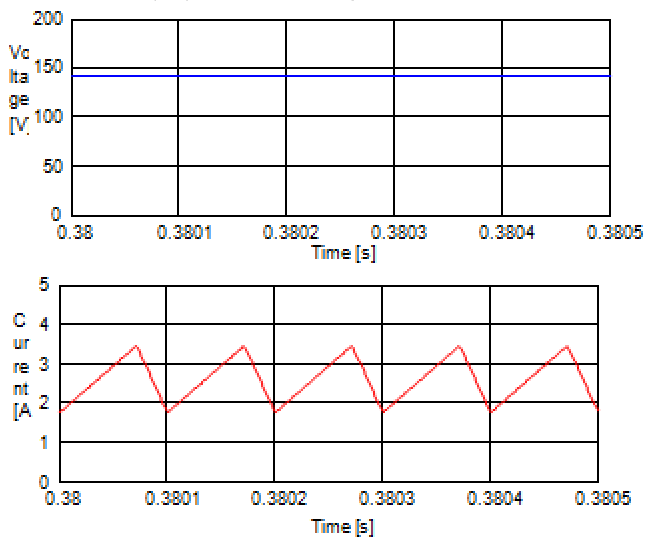



**Figure 9:** Simulation results of the input current and output voltage

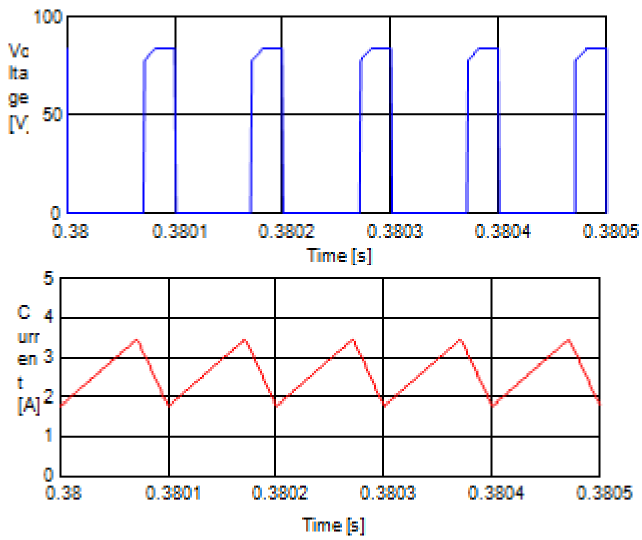



**Figure 10:** Simulation results of the input current and voltage across the power switch S.



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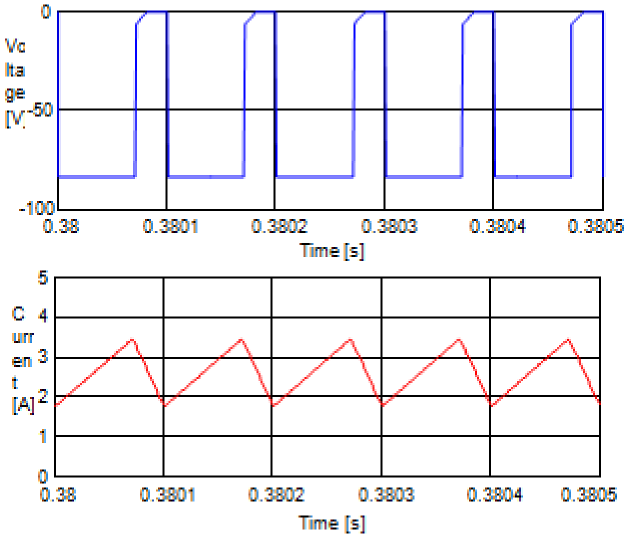



**Figure 11:** Simulation results of the input current and voltage across the diode $D_1$.

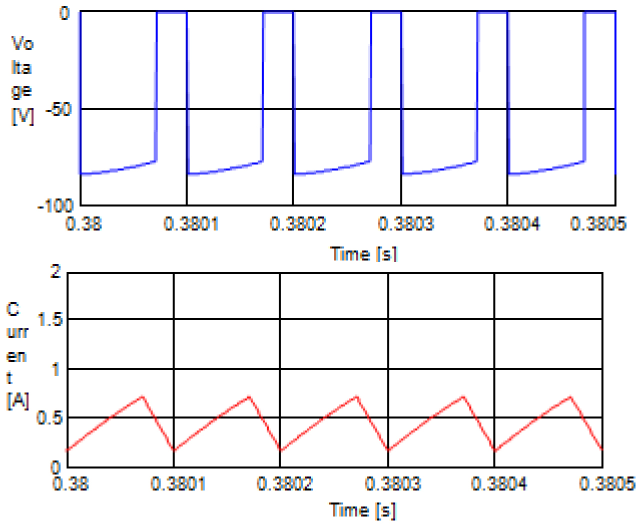
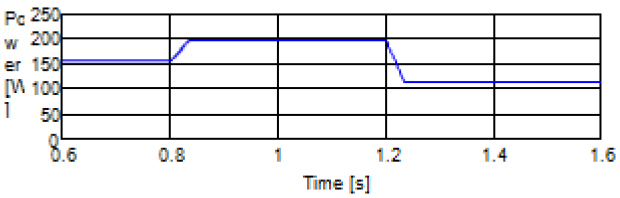



**Figure 12:** Simulation results of the output current inductor ($i_{L2}$) and voltage across the diode $D_2$

**Table 2:** Parameters of the PV array

| | |
|---|---|
| Peak power | 200w |
| Maximum power Current (Impp) | 7.61A |
| Maximum power Voltage (Vmpp) | 26.3V |
| Short-circuit current | 8.21A |
| Open circuit voltage | 32.9V |
| $I_{cc}$ temperature coefficient | 3.18mA/k |
| $V_{ca}$ temperature coefficient | 123mV/k |
| Number of cells in series | 54 |



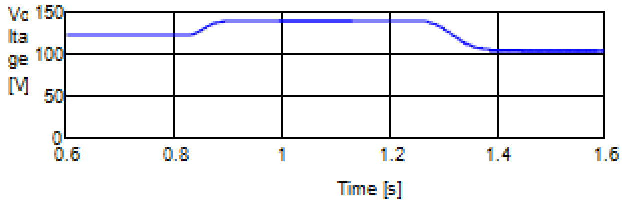




**Figure 13:** Time evolution of the irradiance and power supplied by the solar panel

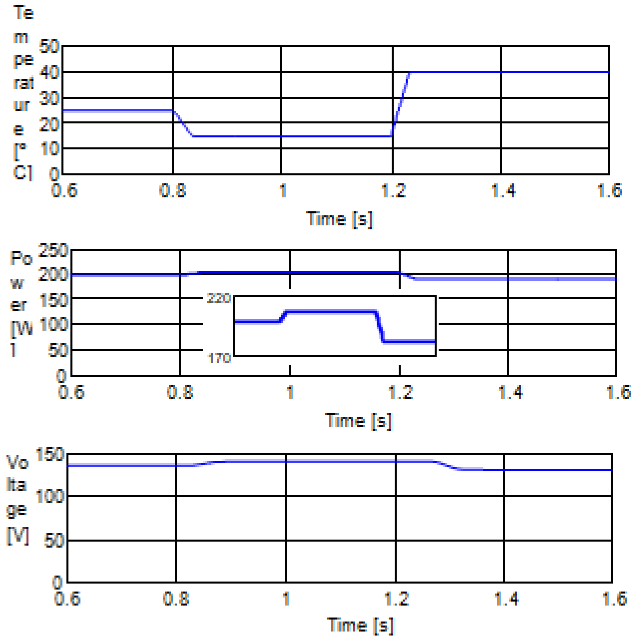



**Figure 14:** Time evolution of the ambient temperature and power supplied by the solar panel

## 5. Results and Conclusion

Tests of the proposed power converter in steady state and in dynamic mode using the program Matlab/Simulink and Power System Toolbox were made. In these simulations the parameters that were used for the proposed power converter were the following: inductors L1 = 1 mH and L2 = 1 mH, capacitors C1 = 100 lF, C2 = 100 lF and C3 = 2 lF and switching frequency of 10 kHz. [9]

Figs. 9–12 show the simulated waveforms for the converter in steady-state and for a 24 V input voltage and a duty-cycle of 0.7. From these results it is possible to confirm that the output voltage is 5.6 times higher than the input voltage (since an output voltage of 136 V is obtained), confirming the theoretical voltage static gain. The continuous conduction mode of the current through the inductor L1 is also verified by these results. The reduced voltage across the semiconductors can also be noted, since the maximum voltages across the power switch S and diodes are 80 V.

The proposed DC/DC converter is also tested in dynamic operation through the use of a photovoltaic module (PV) as the power source. For simulations, a model of the commercial PV module Kyocera KC200GT was obtained from the main data of its datasheet (Table 1). The chosen model is based on the one diode equivalent since is the most important and gives good enough results. A first test was made considering a change in the solar irradiation. Fig. 10 shows the profile that was used in this test. The system was initially operated at 800 W/m2 and at time 0.8 s changed gradually to 1000 W/m2. At time 1.2 s the solar irradiation dropped to 600 W/$m^2$. This test was made for a fixed temperature of 25 C. This figure also shows the power supplied by the solar panel and the output voltage of the converter. Through the analysis of this figure is possible to confirm that the proposed converter associated to the MPPT algorithm responds in accordance with the changes in the irradiation.

Another test was made, but in this case to illustrate the system dynamic behavior under variable temperature. The profile of the ambient temperature that was used in this test is presented in Fig. 14, using the irradiance level of 1000 W/$m^2$. As can be seen by this figure, the system was initially operated at 25 C and at 0.8 s changed gradually to 15 C. Finally, at 1.2 s the temperature increased to 40 C. Although, real world temperature profiles will not change this fast, this profile was chosen to accommodate the small step times (1 ls) needed to describe the switching action of the power devices, which prevent long simulation times due to computer processing power and memory limitations. The time behavior of the PV power in the referred conditions (Fig. 14), shows that the MPPT incremental conductance algorithm extracts the maximum power available at each temperature. The bottom graph of this figure shows the output voltage of the power converter. From the simulations presented in this figure is possible to conclude that the behavior of the variables is in accordance with the expected.

In this paper a new high-gain single-switch non-isolated DC-DC converter is proposed. Thistopology is characterized by the integration of a Boost and C´ uk DC-DC converters, using only one controlled power switch, and is suitable for photovoltaic applications, where low voltage solar panels are used to provide high DC voltages to inverters. The topology enables an extended voltage static gain, when compared with the classical boost converter, while reducing the voltage stress across the power switch and diodes, being smaller than the output voltage of the converter, and therefore lower than on an equivalent boost converter. The presented steady-state operating analysis considering nonideality of some components concluded that a gain slightly lower than 6 can be obtained for duty-cycles near 0.7. An MPPT algorithm was presented to be applied to conventional PWM modulators to control the proposed converter. Simulation and experimental results were presented in order to confirm the characteristics of the proposed topology (5.6 gain) as well as its capability to track the maximum power point of a photovoltaic panel.

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