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Comparison of Real-Time Performance Between ĆUK and SEPIC Converters for an MPPT Based on the P&O Method Using Xilinx System Generator

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Abstract - **Today, the electrical energy extracted at the output of photovoltaic panels is still low despite the significant efforts made in the development and improvement of the converters in the photovoltaic field. In addition the maximum energy extraction is also achieved using a Maximum Power Point Tracking (MPPT) method that could increase the electrical power efficiency and also significantly reduce the overall cost of a photovoltaic system. However, this paper compares the performances of two main and popular converters, the ĆUK and the SEPIC which monitor the MPP of the photovoltaic (PV) system. As a result, the advantages and disadvantages between the two converters have been described and discussed. The results of the simulation showed that the ĆUK and SEPIC converters followed the MPP with a very small gap difference. The experimental simulation system was developed using Matlab/Xilinx System Generator (XSG) for the operation of the proposed algorithm and the architecture structure was developed in the XSG environmental tool for its implementation on an FPGA device with a minimal resource. Thus, the current research work was completed using a minimal resource and led to a simple and inexpensive system.**

Keywords: **Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Perturb and Observe, ĆUK and SEPIC converters, Xilinx System Generator.**

I. INTRODUCTION

The sun is an inexhaustible source of energy, it is naturally regenerated in a short time, for this reason, it is called "renewable energy" or "sustainable energy". Due to the gravity of the global energy crisis and environmental pollution, the photovoltaic (PV) system has become a kind of important source of renewable energy. Solar energy has important advantages, a maximum reserve, inexhaustible, without geographical limits, it is thus the photovoltaic technology of our day becomes a vast subject of popular research. On the other hand the oil reserves would have been exhausted in 2040, the natural gas in 2060, and the coal in 2300 [1]. In Algeria, the authorities have become aware of this challenge, renewable energy objectives will be doubled (12-25) GW by 2030 [2], the country has about 350 MW of photovoltaic projects under development.

A tariff system offers surrender rates of approximately US $ 0.20 for (1-5 MW) projects and a slightly different rate for projects over (5 MW). Currently research work has focused on how to extract more efficient power from photovoltaic cells. The efficiency of PV systems is still low due to the influence of changes in insolation and temperature. To improve the efficiency of a PV system, monitoring of the maximum power point is essential in order to obtain maximum energy from the PV system. Since 1968, the date of the first publication of the control law on the MPPT algorithm, research work has continued to appear [3]. Different types of powerful algorithms on PPM research are cited in the literature [4] [5].

There are many MPPT algorithms such as Perturb and Observe (P&O), Incremental Conductance (IC), fraction of short-circuit current, fraction of open-circuit voltage, neural networks and fuzzy logic, ext ....
In [6] the concept of power monitoring for photovoltaic systems is highlighted and an overview of 40 old and recent maximum power point tracking (MPPT) methods, available in the literature, is presented and classified. The Perturb and Observe method presents a problem in determining the optimum operating point in rapid changes in sunlight, but is easier and more reliable under normal conditions [7] [8] [9] [10]. DC-DC converters act as interfaces between the load and the photovoltaic module. They are generally used as a means of MPPT research as needed. For example the Boost converter is used in the case of raising the output voltage. But in other cases the desired output voltage must be lower than the input voltage [11]. In [12], the comparative analysis between the SEPIC topology and the ĆUK topology is presented. The ĆUK and SEPIC converters operate on the principle of energy transfer using capacitors and inductors to reduce current ripple in the circuit. In this article, the comparison of real-time performances between two converters, ĆUK and SEPIC for a MPPT based on the P&O method is studied and implemented using Xilinx System Generator.

For integration on a single chip, FPGAs offer lower implementation costs than microcontrollers and DSPs. FPGAs can provide equivalent or better performance than ASICs. FPGAs also offer the advantage of being

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reprogrammed at any time while the system is running thus providing a high degree of robustness. In addition to robustness and reprogramming, FPGAs can also provide a high level of flexibility [13]. Therefore, to meet the required performance, FPGAs are desirable since their performance can easily outperform the performance of microcontrollers and DSPs.

II. MODELING A PANEL (PHOTOVOLTAIC CELL)

A photovoltaic cell can be compared to the equivalent circuit shown in Fig. 1 [14].

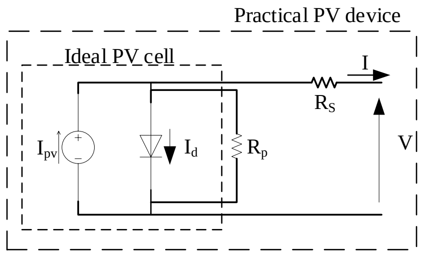

Fig. 1 Circuit equivalent to a single diode of a PV cell

To model the cell, the electrical quantities represented in the circuit above are expressed in the form of an equation, the current in the diode is expressed by:

$$I_D = I_0 \left[exp\left\{\frac{V_D}{V_T}\right\} - 1\right] = I_0[exp\left\{\frac{(Vpv+Ipv*Rs)}{V_T}\right\} - 1] \quad (1)$$

Io is the saturation current of the reverse polarization of the diode.

Avec:

$$V_D = (Vpv + Ipv * Rs) \quad (2)$$

And V_T is the thermal tension defined by:

$$V_T = \frac{kT}{q} \quad (3)$$

With k the Boltzman constant equal to $1.3806503\text{x}10^{-23}$ J/K, T is the operating temperature of the cell in Kelvin degree, and q the charge of the electron. The voltage Vpv is given by:

$$V_{pv} = (V_D - Ipv * Rs) \quad (4)$$

And:

$$I_p = \frac{V_D}{R_p} = \frac{Vpv}{R_p} + \frac{Rs}{R_p} I_{pv} \quad (5)$$

Finally, we obtain the expression of the current I_{pv} of the cell:

$$I_{pv} = I_{sc} - I_D - I_p = I_{sc} - I_0[exp\left\{\frac{(Vpv+Ipv*Rs)}{V_T}\right\} - 1] - \frac{Vpv}{R_p} - \frac{Rs}{R_p} I_{pv} \quad (6)$$

Photovoltaic cell can not provide enough power to power a load or power grid. It is therefore necessary to assemble several cells in series and in parallel in order to obtain more power. A serial connection increases the output voltage of the solar panel, while a parallel combination increases the current supplied to the load. Then, it is necessary to introduce two new parameters Np and Ns respectively represent the number of cells in parallel and in series. The expression of the current I_{pv} becomes:

$$I_{pv} = N_p I_{sc} - N_p I_0[exp\left\{\frac{(Vpv)}{N_s V_T} + \frac{(Ipv*Rs)}{N_p V_T}\right\} - 1] - \frac{Vpv}{R_p} - \frac{Rs}{R_p} I_{pv} \quad (7)$$

With:

- Isc: Short circuit current of the cell;
- Rp: The resistance characterizing the carrier recombination losses due to defects in the material;
- Rs: Characterizes the Joule losses in the semiconductor and the losses through the gate and the bad ohmic contact of the cell.

The amount of solar radiation directly affects the production of charge carriers in the solar panel, therefore affects the current produced by the latter, its expression is given by:

$$I_{os} = Irs\ [T/Tr]^3 \ \exp\left[q * \frac{E_{G0}}{\beta * K}\left\{\frac{1}{Tr} - \frac{1}{T}\right\}\right] \quad (8)$$

And:

$$I_{sct} = [I_{sc} + K_I(T - 298.15)]\frac{G}{1000} \quad (9)$$

Tr : is the reference temperature (K = 298.18), (E_{G0} = 1.12 eV) is the width of the silicon band, (β = 1.740) the ideality factor, Irs is the reverse saturation current of the cell, Ios is the saturation current of the cell.
In this comparison, we deliberately chose the monocrystalline photovoltaic solar panel Atersa A-250M. This is one of the modules used in the Ghardaia station in southern Algeria. It has a high efficiency, its value is highly competitive. In addition, these modules are covered by a 10-year guarantee [15].

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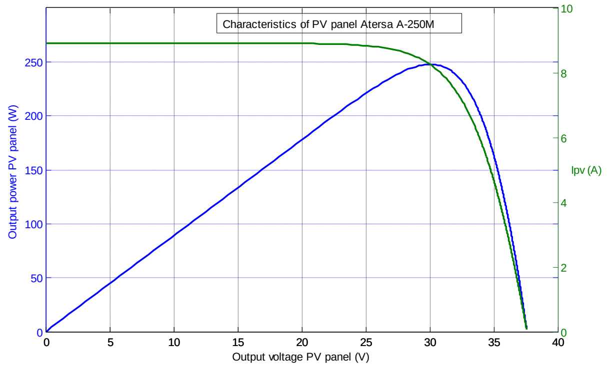

Fig. 2 Characteristics of PV panel

Table. I below summarizes the manufacturer's data. Based on the parameters of the table. I, the PV module is modeled in the Matlab/Simulink environment for standard test conditions (STC) of 25 ° C and 1000 W/m2. Fig. 2 above shows the characteristics of the Atersa-250M panel under standard conditions (G = 1000w / m2, T = 25 ° C).

TABLE. I ELECTRICAL AND THERMAL CHARACTERISTICS OF THE PANEL A-250M (STC: 1Kw/m2, 25 ° C ± 2 ° C)

Nominal power	250 W
Module efficiency	15.35%
Open circuit voltage	37.62 V
Voltage at the point of maximum power (Vmp)	30.35 V
Short circuit current	8.79 A
Current at the point of maximum power (Imp)	8.24 A
Coefficient of temperature voltage Voc (β)	-0.34%/°C
Current temperature coefficient Isc (α)	-0.03%/°C
Power temperature coefficient P (λ)	-0.43%/°C

III. TRACKING MAXIMUM POWER POINT (MPPT)

A. MPPT charge regulator

The technique (MPPT) is used to couple the inverters to power grids, solar battery chargers and similar devices in order to obtain the maximum possible power from one or more photovoltaic devices. The photovoltaic cell has a non-linear current/voltage characteristic as a function of the insolation and the temperature of the cell. The role of the MPPT is to ensure a coherent adaptation between the solar panel and the converter by generating an appropriate command to deliver the maximum power to the load whatever the climatic variations of the insolation and the temperature. MPPT devices are generally integrated into power conversion systems. In addition they ensure the regulation of the voltage and the current provided whatever the variation of the load or the network to feed [16] [17].

B. MPPT techniques

Maximum Power Point (MPP) tracking is the automatic control algorithm to adjust the power interfaces and achieve the greatest possible power extraction, regardless of the changes in insolation and temperature or the effects the shading. This is therefore to ensure the operation of the system at the PPM point under varying atmospheric conditions. The MPPT then became an essential element for evaluating the performance of PV power system design [18]. There are different techniques used to track the maximum power point. Among the most widely used techniques are: disturbances and observations, incremental conductance, the fraction of the circuit current, the fraction of the open circuit voltage, the neural networks and the fuzzy logic. The choice of the algorithm depends on the complexity and execution time of the algorithm for monitoring the PPM, the cost of the algorithm and its implementation [19]. In this article the P & O technique (perturbe and observer) is used and implemented on FPGA target.

C. Description of the adopted algorithm

The algorithm called "P & O" is an MPPT command whose operation is based on the disturbance of the voltage V_{pv}, by increasing or decreasing it by a small amplitude around its initial value [20][21]. This disturbance has the effect of acting directly on the duty cycle of the signal controlling the DC-DC converter. The disturbance is followed by the observation of its impact on the power output of the PV panel, with a view to a possible correction of this duty cycle. The figure. 3 shows the flowchart describing the algorithm providing this command called "P & O". The "P & O" method is widely used today because of its simplicity of implementation. However, this technique has some problems related to oscillations around the PPM it generates in steady state, because the search procedure of the PPM must be repeated periodically, forcing the system to oscillate permanently around the PPM. These oscillations can be minimized by reducing the value of the disturbance variable. However, a low increment value slowed down the search for the PPM, so you have to find a compromise between accuracy and speed. Which makes this order difficult to optimize.

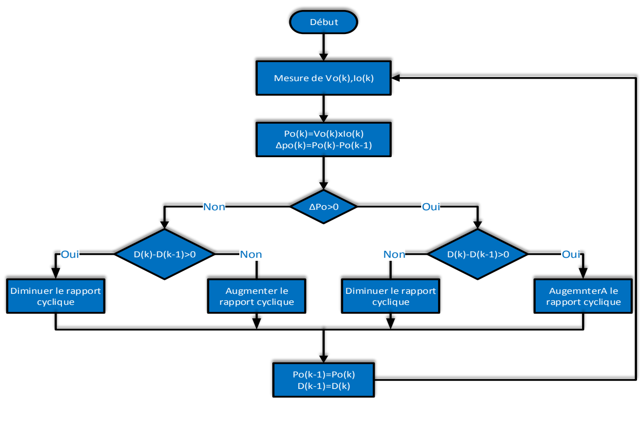

Fig. 3 Flowchart of P&O Algorithm for MPPT control

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D- DC-DC converter design

When proposing a PPM follower, the main task is to choose and design a very efficient converter, which is supposed to function as the main part of the MPPT. Most DC-DC converters are well designed to work with high efficiency.

1) *ĆUK CONVERTER*

The ĆUK converter has a special configuration. It is new compared to other converters. Originally, this converter was developed to generate a high output voltage. In addition, the setting of the output voltage is better than the buck converter and boost converter, as is the case with the Buck-Boost converter, and that's one of the reasons that makes it so popular. The second consideration is that in the continuous conduction mode, the input and output currents are not wavy and reduce electromagnetic interference (EMI). But the disadvantage of this circuit is that it provides, at the output, a voltage whose polarity is opposite to the input voltage [22]. The ĆUK converter has low switching losses and higher efficiency. It can provide better current efficiency due to the inductance of the output stage. Essentially, the ĆUK converter consists of two stages, an input stage and an output stage. Fig. 4 illustrates the circuit of the converter ĆUK.

2) *SEPIC CONVERTER*

The SEPIC converter is a DC-DC converter that converts a DC voltage into another DC voltage of different value (lower or higher). SEPIC is similar to buck-boost but has the advantage of having a non-inverted output (the output voltage is of the same polarity as the input voltage) [23]. This montage was developed by Slobodan ĆUK in the late 1970s. The basic diagram is illustrated in FIG. 5, it consists essentially of three capacitors (Cin, C1, and C2), two coupled inductances (L1 and L2), and a transistor (switch) and a diode. Both ĆUK and SEPIC converters operate at minimum values of their parameters as shown in the table. II below.

TABLE. II DESIGN PARAMETERS FOR BOTH CONVERTERS SEPIC AND ĆUK

components	values	
	SEPIC	**ĆUK**
L1	293.8 µH	450 µH
C1	300 µF	0.21 µF
L2	293.8 µH	925 µH
C2	150 µF	0.88 µF

IV. COMBINED SYSTEM MODLING OF SEPIC AND ĆUK CONVERTER

Modeling of the system using Matlab/Simulink includes: the modeling of the photovoltaic system based on the equations (1) - (9), on the other hand the MPPT controller

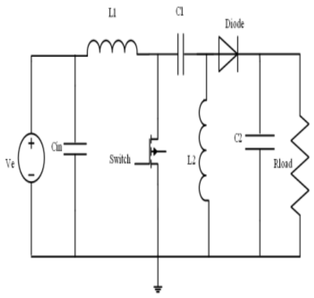

Fig. 5 Circuit diagram of SEPIC converter

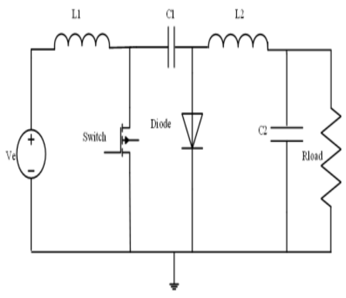

Fig. 4 Circuit diagram of ĆUK converter

based on the flowchart of Fig. 3 is modeled using the Xilinx System Generator environment. The adopted parameters of the two converters are summarized in the table. II. Figure 6 shows the combined system modeled to compare the two systems. Both systems are exposed to the same weather conditions (temperature and insolation) and also have the same PV parameters.

V. RESULTS AND DISCUSSIONS

Fig. 6 below shows the schematic diagram of the principle of the entire photovoltaic generator system. The different blocks essentially constitute the PV panel, the MPPT algorithm, the two DC/DC converters connected to a resistive load. As we mentioned above in the previous section, the controller is designed in the Xilinx System

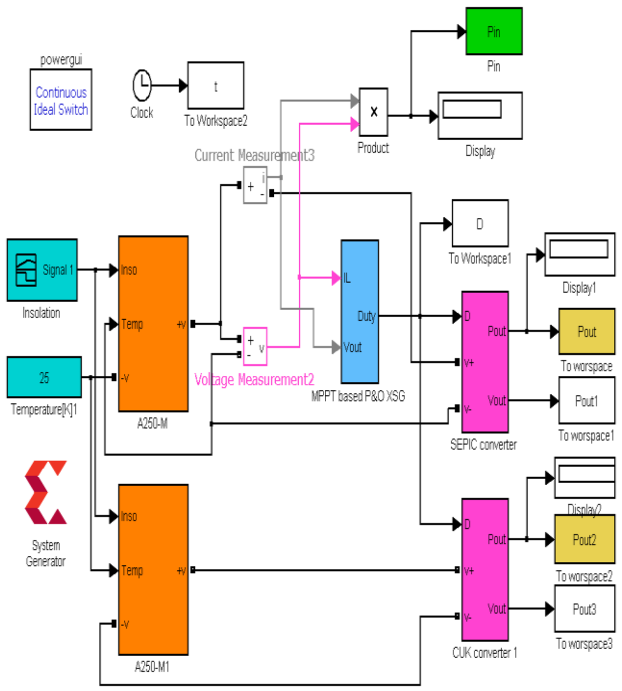

Fig. 6 General architecture of system simulation

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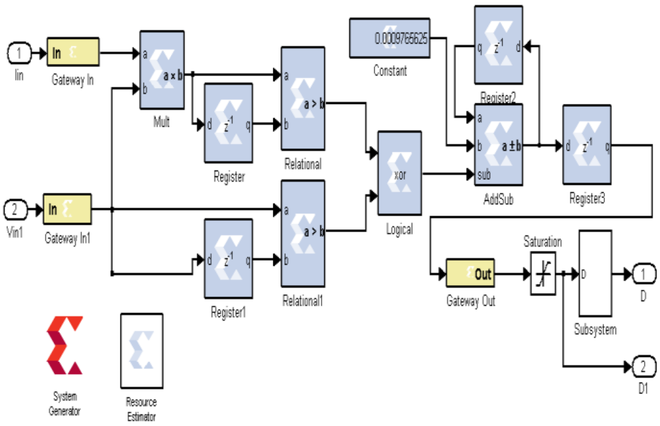

Fig. 7 Implementation of the P&O algorithm based XSG

Generator environment and the results are validated for both converters. Fig. 7 above shows the Xilinx System Generator architecture adopted for the implementation of the MPPT algorithm.

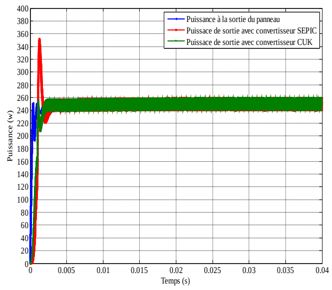

Fig. 8 Power output at constant temperature of 25°C and constant irradiance of 1 kW/m^2

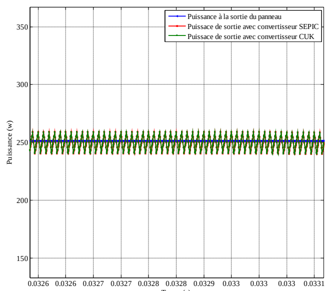

Fig. 9 Expanded time scale waveform at constant temperature of 25°C and constant irradiance of 1 kW/m^2

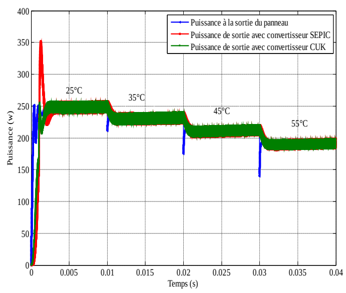

Fig .10 Output power at variation of temperature and constant irradiance of 1 kW/m^2

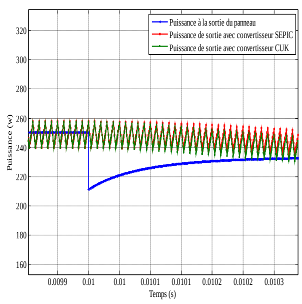

Fig .11 Expanded time scale waveform of output power for a step change of temperature from 25 ° C to 35 ° C and constant irradiance of 1 kW/m2

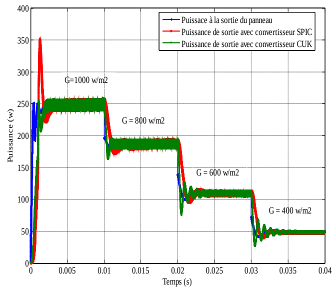

Fig .12 Output power at constant temperature of 25 ° C with step changes of irradiance

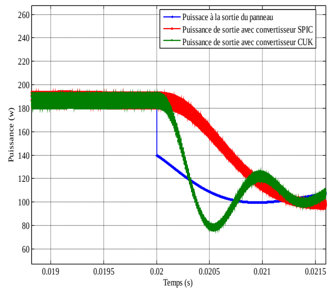

Fig .13. Expanded time scale waveform of output power at constant temperature 25 ° C with step change of irradiance from 800 W/m2 to 600W/m^2

During implementation, the main problem encountered lies in the implementation of complex functions given the limited number of these functions that an FPGA contains. These functions increase the execution time and the space used on it. Nevertheless, there are practical approaches to bringing these functions together with simple FPGA designs. In [24], a simple and improved integral function model has been presented in which the equations of the SEPIC converter have been simplified to fit for FPGA implementation. In [25], the presence of the exponential function in the equation describing the current-voltage characteristic (I-V), making it difficult to locate the optimal point thanks to its first derivative, the Cubic Natural Spline Method is used.
Given the high speed of the FPGA for data processing on the one hand, and the maximum delays that can cause the analog/digital converters. So we have choose a CAN that ensures a good synchronization with the FPGA. In our circuit, an 8-bit ADC (TDA8703) is used which can sample the input signal at a rate of 4.43 MHz. Fig. 14 summarizes the system's circuit adopted with an integrated controller on an FPGA. The CANs are the link between the analog part and the digital part.

A used resources

The use of FPGA resources is a key measure to materialize a system. Reducing the resources used is particularly important when the goal is to find the best behavioral performance of the system. The results are obtained using Xilinx Sysrem Genrator [26], the synthesis is ensured with the ISE 12.3 in the target SPARTAN3E xc3s500e-5fg320. The ISE environment, provides an implementation report in the form of tables containing useful information related to the following design: The table. III below counts all internal resources used in number and percentage of MPPT P&O controller.

B routing

Routing is an Important Step in Developing an architecture for FPGA Target Implementation. It consists in creating physical connections between the logical elements of

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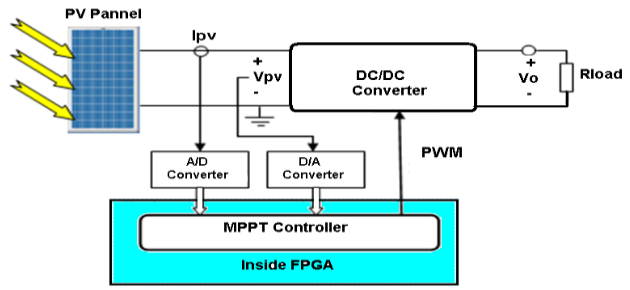


Fig.14 Diagram of the principle of the adopted PV system with integrated controller on FPGA

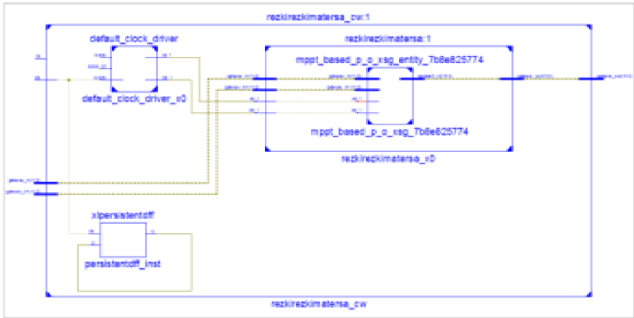


Fig. 15 Global RTL scheme of the P & O algorithm

the FPGA by respecting the parameters of the architecture [27]. Each signal must therefore be connected to the FPGA routing resources. After these simulation results, the design was synthesized, a system-wide bitflow device was generated. It has been verified successfully by downloading it on the FPGA target mentioned above. The overall and internal diagram of the architecture of the proposed P&O algorithm is shown in FIG. 15 below. Fig. 16 shows the routing of the FPGA circuit for the "MPPT P&O" controller program.

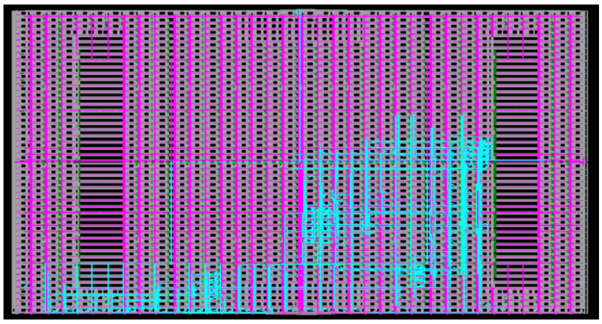
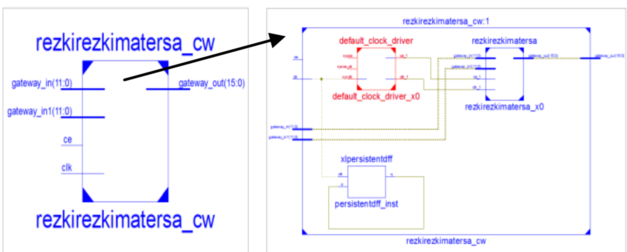


Fig. 16 FPGA circuit routing for the MPPT P&O controller program

Table. III Resources used for the P&O algorithm

Logic Utilization	Used	Available	Utilization
Number of Slice Flip Flops	52	9,312	1%
Number of 4 input LUTs	53	9,312	1%
Number of occupied Slices	44	4,656	1%
Number of Slices containing only related logic	44	44	100%
Number of Slices containing unrelated logic	0	44	0%
Total Number of 4 input LUTs	53	9,312	1%
Number of bonded IOBs	41	232	17%
IOB Flip Flops	16		
Number of BUFGMUXs	1	24	4%
Number of MULT18X18SIOs	1	20	5%
Average Fan out of Non-Clock Nets	1.45		



We analyze the simulation results described in Figures 8 to 13, we can conclude that:

- The MPPT algorithm (Perturb and Observe) reaches the maximum power point (PPM) very fast for both converters ĆUK and SEPIC.
- Both systems respond to changes in temperature and irradiation.
- The output power of the system for the SEPIC converter has a 40% overshoot, but no overrun is recorded for the converter ĆUK.
- The rise time for both converters is almost the same, its value is 0.55ms.
- The output power of the system is more stable with the SEPIC converter at the point of maximum power compared to the system with the converter ĆUK.

VI. Conclusion

This study compares the performance of two converters ĆUK and SEPIC used for the design of a MPPT using the P&O (Perturb and Observe) technique. The MATLAB/ Simulink software was used to simulate the system including the two converters and the photovoltaic module. On the other hand, the MPPT algorithm is executed in the XSG environment. The research work is carried out with minimal resources, making the system easy to implement on target FPGA and is therefore inexpensive. The results show that the output power of the ĆUK convertor is greater than the one of the SEPIC convertor within a short period of time. They also show that both systems easily detect the maximum power point in a period of time less than 0.005s. The ĆUK converter

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is much more stable with less power drive at the PPM position than the SEPIC converter.

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