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The Transition to Renewable Energy for A Green Shoot of Economic Revival: Comparative Study of Four MPPT Control Algorithms for A PV System

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ABSTRACT

This paper explains the need for renewable energies for "green revival" of the economy. First, we will analyze the overall context of the double crisis. Then we will focus on "green recovery" as a solution for these two crises. Finally, we will study the example of the photovoltaic system as a source of renewable energy by presenting and comparing four types of MPPT commands such as: Perturb and Observe, Incremental Conductance, Fractional Open-Circuit Voltage (FOV) and Fractional Short-Circuit Current (FCC). The Matlab-Simulink environment will be used to analyze and interpret the simulation results of these algorithms and therefore we show the performance and limits of each algorithm.

Keywords: renewable energy; economic crisis; climatic crisis; PV; green economy; green recovery; MPPT; PO; INC; FOV; FSC

INTRODUCTION

Interest in renewable energies is relatively recent. Before the 1973 oil shock, no developed country was interested in alternative energies. Each country exploited the sources of energy readily available to it: coal in Great Britain and oil in France, which is mainly imported from Africa. It was only when the price of hydrocarbons quadrupled in a few months that developed countries thought about turning to alternative energies.

Renewable energies are used to meet the same needs as other forms of energy. Indeed, they can be used to generate electricity, in which case they can power homes, buildings, transport and lighting. Renewable energies offer rural territories the opportunity to access a source of energy that is clean and decentralized [2,10].

In recent years, the transition to energy system based on renewable energies such as photovoltaic energy has emphasized the emergence of the concepts of "green recovery" and "green economy" which have gained traction magnitude with the economic crisis of 2008 and its consequences which are still present today [12]. Indeed, the economic crisis of 2008, which is the most serious since that of 1929, was caused by the subprime market in the United States [7].

This crisis has been characterized by a fall in aggregate demand which is accompanied by rising unemployment rates all over the world. In order to get out of this crisis, several economists have suggested resorting to "green stimulus" which simultaneously revives the global economy, creates "green" jobs and protects the environment [1].

In this context, we are interested to improve the efficiency of photovoltaic panels that present a renewable energy source, so it is necessary to optimize the design of all parts of the PV system. In addition, it is necessary to optimize the DC/DC Boost converter used as the interface between the PV generator and the load in order to extract the maximum power and thus operate the PV generator at its maximum power point (MPP) using an MPPT controller (Maximum Power Point Tracking), therefore, a maximum electric current is obtained under the variation of the load and the atmospheric conditions (radiation and temperature) [17].

This paper is organized as follows. In section 2, we present the context of double crisis. In section 3, we introduce the green recovery as a solution for both crises. The photovoltaic generator and the studying of different MPPT algorithms as Perturb and Observe (PO), Incremental Conductance (INC), Fractional Open-Circuit Voltage (FOV) and Fractional Short- Circuit Current (FSC) are described in section 4.

Then we discuss the numerical simulation results of PV system connected with different MPPT algorithms in section 5. bankruptcies in the context of small and medium-sized enterprises, which are often the most vulnerable.

Finally, conclusions are drawn in the final section.

THE CONTEXT OF DOUBLE CRISIS

The world is facing two crisis of different types, one of an economic nature while the other is more climatic. Indeed, the financial crisis that began in the United States quickly spread to other countries and within months it turned into a global economic crisis. Despite the gravity of the economic crisis, the fight against climatic change must always remain a primary and urgent concern for all countries [1]

1) The economic crisis

As is well known, the US real estate market played a crucial role in triggering the financial crisis and this has been detailed by several authors (Bernanke, 2009; Foster and Magdoff, 2009; Gokhale, 2009). Indeed, the financial crisis has its origins in the subprime market in the United States. This market consists of granting pledged loans on residential real estate to customers who are generally not very solvent.

The continuity and success of this system depends largely on the price of real estate which is assumed to be continuously increasing and also on the stability of interest rates [7].

Unfortunately, these two conditions disappeared at the same time as the price of real estate fell sharply and the key rate rose continuously. Faced with these two unexpected events, households found themselves unable to pay their loans.

As a result, the banks carried out a massive sale of the foreclosed homes which caused the real estate prices to drop.

In the summer of 2007, there was the onset of the financial crisis. The two main causes of the speed of transmission and the severity of the subprime mortgage crisis are debt securitization and investment funds. This crisis has caused enormous losses to banks which are estimated at around 950 billion dollars worldwide [International Monetary Fund (IMF), 2008]. In September 2008, two major bankruptcies marked the spirits: the collapse of "Lehman Brothers" which is an American investment bank and the rescue of the insurance giant "American International Group" (AIG) which was at the end of bankruptcy [16].

As a result of these two events, there were further bankruptcies and bailouts of financial institutions in both developed and developing countries. Thus, what started as a crisis in one sector has become, according to (Omarova, 2009) "the world's first truly global financial crisis". Following the bankruptcies of several financial institutions, the real sphere was also affected by the banking crisis, which led to mass

Most developed economies have suffered severe recessions with rising unemployment rates and falling aggregate demand. According to the International Labor Organization (ILO, 2010), the number of unemployed people is estimated at 212 million in 2009, which means an increase of 34 million compared to 2007.

600,000 people lost their jobs in the United States in January 2009, the most serious monthly loss since 1974. We also saw the loss of about 3.6 million jobs between December 2007 and January 2009 (ILO, 2009). As a result, world trade in manufactures fell with repercussions for the economies of East Asia. At the same time, falling commodity prices have affected countries in Africa, Latin America and the Middle East. According to the World Bank, 2008, every 1% drop in the growth rate in developing economies creates 20 million people predestined for poverty [19].

2) The climatic crisis

The United Nations Framework Convention on Climatic Change (UNFCCC) is the first convention established by the United Nations with the aim of a better understanding of the phenomenon of climatic change and the search for adequate strategies to do so face [13].

The climatic change concerns all the intense changes that have affected the climate such as increased temperatures, cyclones. But the term climate change is often used to designate the warming of the planet caused mainly by emissions of gas to greenhouse effect.

Awareness of the dangers of global warming took place during the 1960s and 1970s. During this period, the scientific community demonstrated the fragility of the ecosystem and the dependence of our well-being on climatic change.

As temperatures continue to rise, climatic change is likely to be unmanageable. This serious global threat can push ecology to unknown tipping points that can fundamentally and irreversibly change the way our planet functions (Lenton et al., 2008). Indeed, results obtained from a number of studies have indicated that climatic change is occurring much faster than expected. In particular, the Antarctic ice began to disappear at a rate much faster than that predicted by scientists (UNEP, 2009) [21].

Although there is global awareness of the dangerousness of climatic change, the actions taken are not enough. Indeed, policymakers tend to focus on the short term and try to solve pressing economic and financial problems. The scope of the task and the difficulty of coordinating and setting up a system to combat climatic change also contribute to slowing the fight against this phenomenon.

GREEN RECOVERY AS A SOLUTION FOR BOTH CRISIS

Since the economic crisis, many international organizations have insisted on the need for expansion of investment in the renewable energy sector, in all countries, in order to stimulate the economy, create jobs and mitigate climatic change. As a result, many UNEP reports (2009; 2010; 2011) see the economic crisis as an opportunity to move towards "a green recovery" of the economy. As a result, we have seen the emergence of the UNEP "green economy" initiative (UNEP, 2011) and the OECD "green growth" strategy (2011).

In this context, several international organizations have called for the implementation of a "green recovery" program or a "green new deal" which is made up of a set of strategies that both allow the economy to revive and environmental protection; it is therefore a "green stimulus" for the economy. The expansion of the renewable energy sector is therefore an essential element of all these strategies [4].

Global investment in the renewable energy sector according to Figure 1, excluding large hydropower projects, was around 270 billion dollars in 2014, noting a growth of 17% from the level of investment in 2013. This is the first increase recorded since the 2011 record. The best results recorded in 2014 are due to the increase in solar installations in China and Japan as well as offshore wind projects in Europe (UNEP, FSFM and BNEF, 2015).

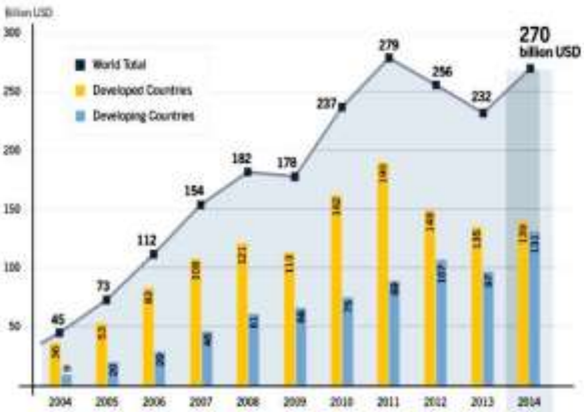

FIGURE 1: Global new investment in renewable power and fuels, developed and developing countries, 2004-2014.

Renewable energies in 2014 represented 58.5% of the electricity capacity added worldwide. Wind power, PV power and hydropower accounted for the highest share of installed capacity (REN21, 2015). Another key feature of this year is the continued spread of renewable energy to new markets. Indeed, investment in developing countries reached 131.3 billion dollars, registering an increase of 36% compared to 2013. On the other hand, investment in developed countries, it is around 138.9 billion dollars according to Figure 1.

The decrease in the costs of solar and wind energy technologies made it possible to achieve strong momentum for these two technologies in 2014. Indeed, investment in solar energy reached 149.6 billion dollars with an increase of 25 % compared to 2013, while investment in the wind energy sector increased by 11% compared to 2013, registering a record of 99.5 billion dollars (UNEP, FSFM and BNEF, 2015). 2014 is the year of great achievements for renewable energies. In fact, the level of investment has rebounded sharply after two years of decline, with installed capacity exceeding that of fossil origin. In addition, investment in developing countries led by China has come very close to investment in developed economies [6].

It is clear that the renewable energy market was revived, from 2009, thanks to "green" tax incentives, but this market rebounded again, starting in 2014.

We are interested in the following study of the automatic aspect of the PV system that is based on solar energy by comparing the different known MPPT commands to extract the point of maximum power of the PV system.

PHOTOVOLTAIC GENERATOR

The PV generation system considered in this paper consists of a photovoltaic cell and a DC/DC Boost converter which is commanded with the MPPT algorithm.

A schematic overview of the PV system is presented in Figure 2.

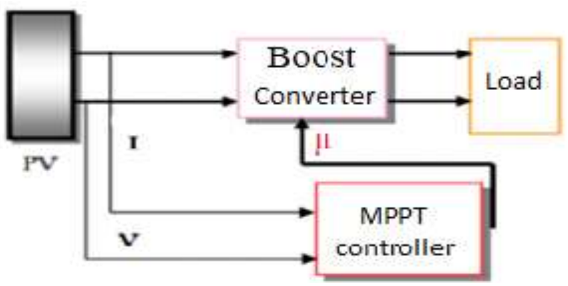

FIGURE 2: Photovoltaic system.

1) Photovoltaic Array

The photovoltaic system is modeled by the following equation [3,8]:

$$I = \frac{qV}{n_p\, I_{ph} - n_p I_{rs}\,(e^{pKTn_s} - 1)} \quad (1)$$

Where n_p and n_s are the number of the parallel and series JK is the Boltzmann's constant, q=1.6

cells, K=1.38 10^{-23}

10^{-19} C is the electronic charge, T is the cell temperature, p is an ideal factor, I_{ph} is the photocurrent and I_{rs} is the reverse saturation current.

The power system of the photovoltaic panel is described by the following equations [2,3]:

$$P = I.V \quad (2)$$

$$I = \frac{qV}{n_p\, I_{ph} - n_p I_{rs}\, V(e^{pKTn_s} - 1)} \quad (3)$$

The PV system will function at the MPP, if the condition dP/dV= 0 is satisfied.

At the MPP and by taking the partial derivate of the power panel with respect to the photovoltaic voltage, we have:

$$\frac{dP}{dV} = 0 \ \rightarrow I + V\frac{dI}{dV} = 0$$

$$\frac{dP}{dV} = I - \frac{n_p q}{p^{KTn_s}}\, I_{rs}\, V e^{\frac{qV}{pKTn_s}} \quad (4)$$

In reason to the high no linearity, the MPP is difficult to be determined from the equation (4). For this cause you must utilize an MPPT algorithm.

2) MPPT algorithms

The Maximum Power Point Tracking (MPPT) algorithm is an essential algorithm for optimal operation of the PV model. The principle of this algorithm is based on the variation of the duty cycle μ in adjusting it to the optimum value to maximize the power delivered by the PV panel [8].

For this reason, we will subsequently study and present the most famous MPPT commands.

2.1) Perturb & Observe algorithm

The principle operation of this method consists to generate a periodic disturbance ΔV on the voltage of the panel. This disturbance will be used to make the decision in the next cycle (observation) [5,9]:

- If ΔP>0 then the voltage disturbance moves the operating point to a point closer to the MPP and we continue to disturb the voltage in the same direction, this will move the operating point until the MPP is reached.
- If ΔP <0 the operating point moves away from the MPP the new disturb the voltage with an algebraic sign contrary to the previous sign to move the operating point until reaching the maximum power point.

In Figure 3, it is given a flowchart which describes the PO algorithm.

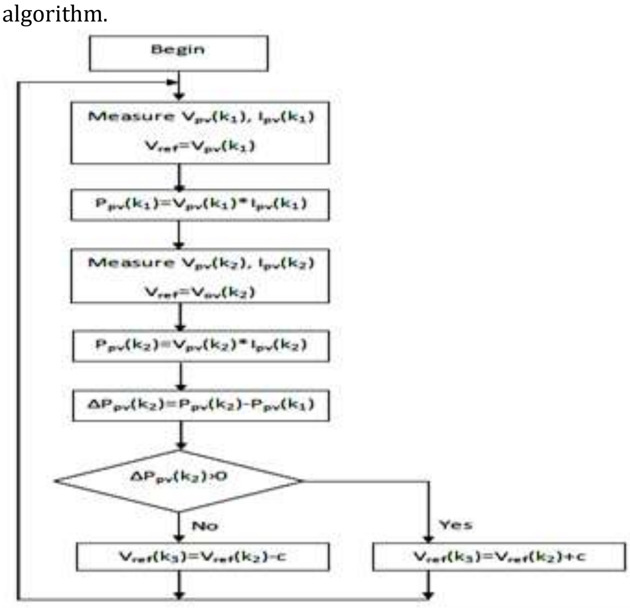

FIGURE 3: Flowchart of the Perturb & Observe method.

2.2) Incremental Conductance algorithm

This command is based on knowing the value of the conductance G=I/V and the increment of the conductance (dG) to deduce the position of the operating point relative to MPP [3,18].

If the conductance increment (dG) is less than the opposite of conductance (-G), the duty cycle is increased. On the other hand, if the conductance increment (dG) is greater than the opposite of the conductance (-G), the duty cycle is reduced. This process is repeated until reaching the MPP. The INC algorithm is shown by the Flowchart in Figure 4.

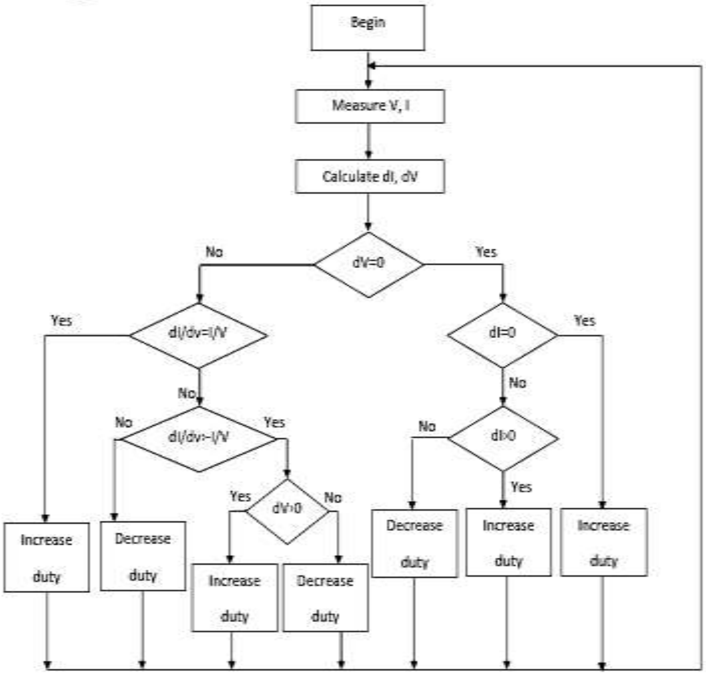

FIGURE 4: Flowchart of the INC method.

2.3) Fractional Open-Circuit Voltage algorithm

The fundamental relationship of the FOV algorithm is presented as follows [11]:

$$V_{MPP} = k_v * V_{oc} \quad (5)$$

Where k_V is a gain factor depending on the characteristics of the PV panel and which varies between 0.73 and 0.8. A Flowchart, which describes the FOV algorithm, is:

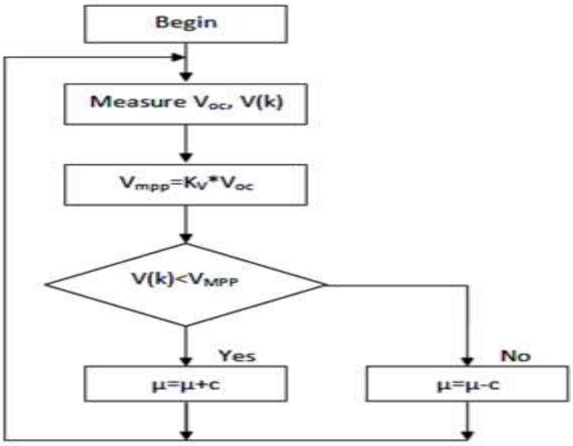

FIGURE 5: Flowchart of the FOV method.

2.4) Fractional Short-Circuit Current Algorithm

The fundamental relationship of the FSC method is defined as follows [15]:

$$I_{MPP} = k_i * I_{cc} \quad (6)$$

Where ki is a gain factor depending on the characteristics of the PV panel and which varies between 0.85 and 0.92. The algorithm of this command is shown in Figure 6.

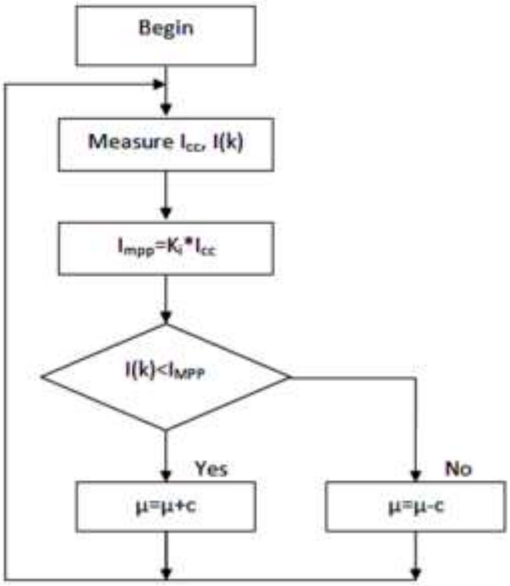

FIGURE 6: Flowchart of the FSC method.

SIMULATION RESULTS

The aim of simulation is to present the behavior of the photovoltaic process under rapid changes of temperature and radiation levels.

So, to demonstrate the performance of the MPPT algorithms that were studied, we apply a sudden change in temperature and radiation.

The evolution of the varying temperature and radiation are respectively given in figure 7 and figure 8.

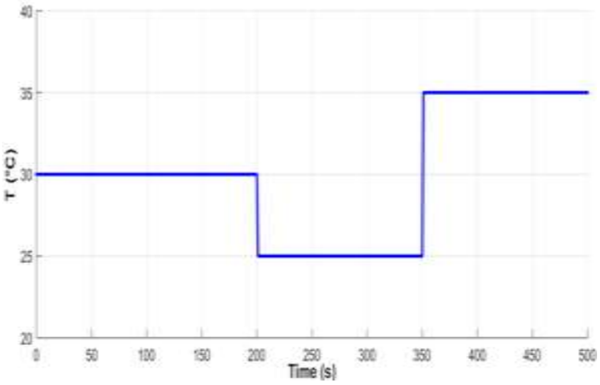

FIGURE 7: Evolution of temperature.

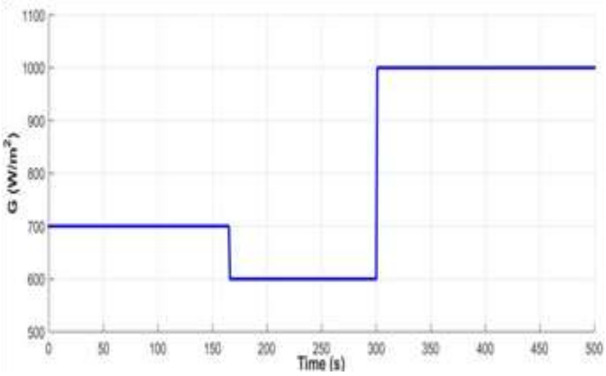

FIGURE 8: Evolution of radiation.

The evolution of PV voltage, the evolution of PV current and the panel delivered power according to the MPPT algorithms studied are presented respectively in Figures 9, 10 and 11.

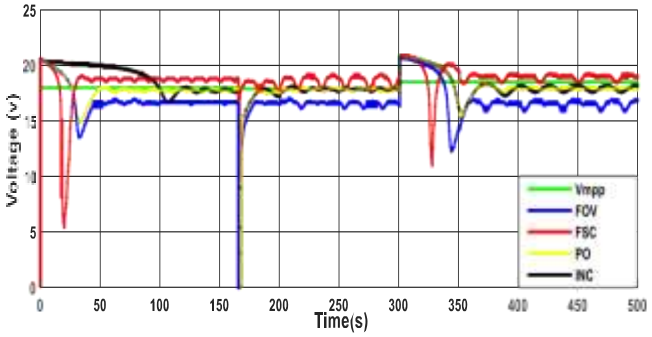

FIGURE 9: Evolution of the voltage for MPPT algorithms.

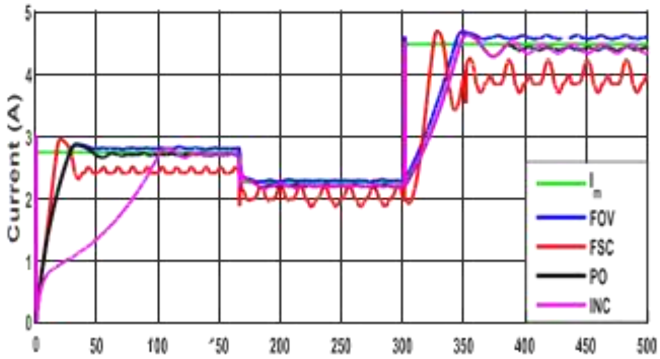

FIGURE 10: Evolution of the current for MPPT algorithms.

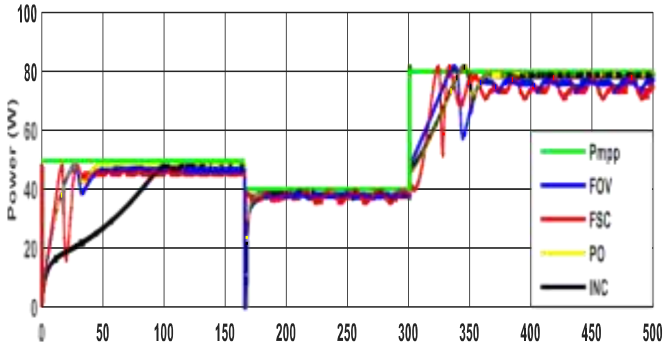

FIGURE 11: Evolution of the power for MPPT algorithms.

The previous simulation Figures show that the photovoltaic process converges to the optimal values.

The "PO" algorithm is a simple command. In general, this command depends on the initial conditions and it presents oscillations around the optimum value. The major drawback of this method is it spoor behavior following a sudden change in radiation.

The "INC" algorithm appears to be an improvement of the "PO" algorithm. This is a more complex command than the previous one. Indeed, it behaves better during a rapid change of metrological conditions.

The algorithms based on measuring a Fractional Open-Circuit Voltage and a Fractional Short-Circuit Current are easy and simple to implement. The major disadvantage of these controls is the stopping of power transfer when measuring the quantities V_{oc} and I_{cc} and the energy losses. To solve this problem, it is possible to use a pilot cell of the same type as the cells of the photovoltaic panel. In addition, the determination of the optimal value of the gain factor k is really difficult.

This is why these methods are just an approximation and they do not have much precision because of the estimation methods of the V_{oc} and I_{cc} parameters and in this case, the photovoltaic panel does not always work at the optimum point.

The table below summarizes the different characteristics of the MPPT algorithms studied previously. These controls were evaluated and compared in terms of technical knowledge of the parameters of the PV panel, complexity, speed of convergence and precision [14,17,20].

MPPT Algorithms	PO	INC	FOV	FSC
Type of sensorsused	1 Voltage 1 Current	1 Voltage 1 Current	1 Voltage	1 Current
Identification of PV panel parameters	Not necessary	Not necessary	Yes necessary	Yes necessary
Complexity	Low	Medium	Verylow	Verylow
Convergence speed	Medium	Medium	Quick	Quick
Precision	95%	98%	94%	94%

TABLE 1: Comparison of MPPT algorithms.

CONCLUSION

In this paper, we first emphasized the need to use renewable energy for a "green recovery" after the economic crisis. Indeed, the economic recession and the severity of global warming are at the root of the adoption of "green recovery" strategies by the international community. In this case, the recovery of the economy after the crisis should be seen as an opportunity to steer the economy towards "green growth". Second, we have described the main elements of the PV system. Next, we recalled the principle of four most popular MPPT algorithms. Finally, we ended with a simulation of the different MPPT algorithms which have showed that the INC algorithm gives good behavior and better performance compared to the other algorithms studied.

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