International Journal of Engineering and Management Research e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-12, Issue-3 (June 2022)
www.ijemr.net https://doi.org/10.31033/ijemr.12.3.20

A Comparison Analysis between a Fixed and Multi-Step Size MPPTs for PV System under Variable Irradiance and Real Solar Curve

Y. AMARA
Electronique Department, Blida university, 09000-Blida, ALGERIA

Corresponding Author: amara.yasmine2019@gmail.com

ABSTRACT

The control of the power electronic interfaces is essential to ensure the high efficiency of the photovoltaic system. In a DC stand-alone photovoltaic system, the boost converter is the most used. A regulator named maximum Power Point Tracking (MPPT) is inserted to control the ON/OFF states. Incremental conductance (In-Cond) is widely used to extract the maximum power point (MPP) from the Photovoltaic panel. It presents more efficiency and reliability compared to the conventional perturb and observes (P&O) technique. However, it presents power loss during the variations appearing during changes in weather conditions, due to the use of fixed step size. Accordingly, the present paper proposes a Multi-step size In-Cond to adapt the PV system to any change of the applied irradiance and to overcome the drawbacks of the existing In-Cond. Indeed, the present contributions introduced two-steps sizes instead of one. The principle is to design a step size value when approaching the MPP and a large value when the operating point is far from the MPP. Simulations and comparisons through MATLAB/Simulink under various applied conditions show that the proposed technique outperforms the conventional Inc-Cond in terms of convergence speed, response time, stability, and performance.

Keywords-- In-Cond, MPPT, Step Size, PV System, Performance

I. INTRODUCTION

In recent years, solar energy is widely explored to meet the increase shown in electrical energy demand. The developing countries adapted special programs to explore this energy since the prices of the PV systems are rapidly decreasing. Unfortunately, solar energy is of unstable nature due to its variable production that is affected by weather conditions, which leads to low efficiency. So, it is required to optimize the output power from the photovoltaic resource. To this end, converters are incorporated to constantly track the Maximum Power Point (MPP) throughout the Maximum Power Point Tracking (MPPT) techniques [1]. The optimization of the harvested power is very important through the MPPT, is very important to ensure the operating process of the PV system. The methods operation principle is based on matching the input and the output converter impedances by sending an adequate current signal to the converter switching gate, so as to, achieve the required voltage output, surely for the same power at both input and output converter sides [2]. In fact, the used power electronic converters interfaces can be divided to three wide families: buck, boost and buck boost converters. These converters contain an inductor (L) that filters its current at its terminal, Capacitor (C) which is in turn filter its across voltage, and a switching component (IGBT or MOSFET) controlled by a current signal for a period (T) to get an adequate voltage and current at its terminals. In another hand, wide ranges of publications are developed to ameliorate the power transfer and stabilize the system, by developing improved or multilevel converters [4]. However, others researchers concentrate on ameliorating the existing MPPTs methods such as Perturb and Observe [5], Incremental Conductance [6], Fuzzy Controller [7]and Neural Network [8]. Typically, the assessment of these methods depends on the specifications of the photovoltaic system, complexity of implementation, the capability of working under any applied condition and its adjustment to any system, and efficiency of the harvested power [7-8]. In fact, conventional MPPTs techniques (i.e. P&O, HC, Inc-Cond) use a fixed step size to get the duty ratio of the DC-DC converter, to get the suitable operating voltage of the PV load. So , the duty cycle value must be selected prudently [1]. It is sure that, a small step value slows the speed of the algorithm during the MPP search process. While, a large step variation causes power loss at steady state which degrades the performance and accuracy of the whole system. In another hand the intelligent controllers such as Fuzzy logic which requires rules and precise design to work .Besides, Neural Network contains hiding layers and based on training every change to get the wanted result. Subsequently, these intelligent techniques can effectively mitigate the problem of using a fixed step value, but, involve supplementary cost and complex the system [9]. As a result, the improvement of the conventional techniques will enhance the robustness and the effectiveness of the PV systems. Authors in [1] reviewed the most widely used conventional MPPTs techniques and made a comparison analysis. In this study, descriptions of the methods accompanied by their flowcharts are clarified. it is noted that the Inc-Cond outperforms the P&O techniques in all performance criteria. In other terms, It can be concluded that either the perturb and observe (P&O) technique is of a simple and low-cost structure, the Incremental conductance (In-Cond) outperforms it in terms of tracking efficiency, stability, and quality.

Moreover, to improve its performance and efficiency modified methods are proposed, which present an improvement on the step size design of the duty cycle by adapting it to the changes that occur at the input MPPT variables. The authors in [10] proposed a modified incremental conductance through variable step size to adjust an automatic step size during the tracking process. Comparison is made with the Conventional incremental conductance where the tracking accuracy and speed are improved. The design, analysis, Simulations and experimental results are analysed. Whereas the authors of [11] proposed an improved low-cost incremental conductance through modifying the structure of the existing incremental conductance. This is done by removing the division calculations and use only the PV power variation (ΔP) and eliminate the voltage variation (ΔV) to simplify the algorithm structure and reduce its cost. Simulations are acquired and experimental confirmation ARDUINO-Uno-board, based on low-cost Atmega328 microcontroller show the reduced steady state power error.

The use of the incremental resistance to adjust the variable incremental conductance step size is analysed and studied in [12], the accuracy and response speed are improved compared with the existing incremental conductance with fixed step size, and this is verified through simulations and experimental validation for large operating range. To design the step size of incremental conductance-incremental impedance is adapted in [13] for a small signal PV model through root locus method. The stability analysis, simulation using PSIM and validation through DSP proved the outperformance of using variable step size instead of the fixed step size of the conventional incremental conductance to improve performances and stability. However, this method is not validated for a large input signal and variable weather conditions. Others improved are report to the existing In-Cond by introducing intelligent controller in hybrid controllers, such as Fuzzy-incremental conductance proposed in [14] which uses a fuzzy control to adjust the step size of the incremental conductance and estimate the duty cycle variations. High performance and stability of the system under standard and variable weather conditions are obtained for a grid connected system. However, the complexity of the algorithm is rising compared to the existing technique. A neural network MPPT is integrated with the incremental conductance, and tested under both uniform and non-uniform irradiance conditions under MATLAB Simulink and implemented using FPGA. Comparisons with P&O Fuzzy based modified HC proved the effectiveness of the proposed technique. However, the complexity and cost were rise [15]. In [16], a PSO is reinitialized using variable step size Incremental conductance for a standalone PV system to ameliorate the behaviour of the system under rapid change of insulation conditions. The design process is based on the introduced system behaviour. The system is validated by MATLAB/SIMULINK. Smaller amount ripples and more accuracy are fulfilled compared to the existing incremental conductance and PSO MPPTs techniques. But, the algorithm will require additional cost for complex structure. Accordingly, in this paper an In-Cond with a Multi-step size is developed and compared to the existing In-Cond which uses fixed step size via the implementation and simulation of the photovoltaic panel with a boost converter accompanied with the MPPTs control techniques in MATLAB/Simulink interface. These MPPTs are compared under standard, real sun curve and variable weather conditions, where, the proposed technique is more efficient and stable in all cases.

The rest of this paper is as follows: Section.II, describes the used system and the designed controllers are described in Section III. Section IV. details different simulations and discussions. Finally, the Conclusion is drawn in Section. V.

II. PHOTOVOLTAIC SYSTEM

The designed Photovoltaic system is depicted in the Fig.1.

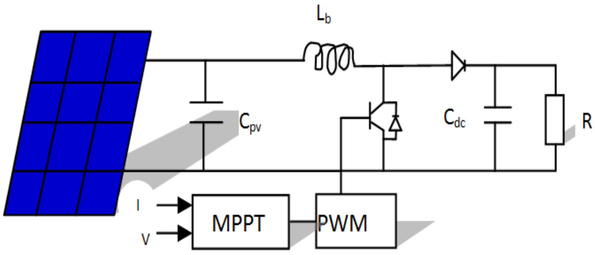

Figure 1: Proposed Photovoltaic System

A. Photovoltaic Cell

The solar cell is composed of a semiconductor materiel capable of transferring the solar irradiance to direct electricity through the photovoltaic effect. The ideal solar cell model does not contain any resistance (series or parallel). while the other solar cell developed such as single diode and two diodes models contain series and shunt resistances. Several manners are adapted to implement and test the solar cell tracking efficiency and improve its structure through mathematical modelling , using the equivalent circuit or components existing in the Simpower of MATLAB/Simulink[17]. Indeed, in order to implement and test the proposed techniques a single solar cell model drawn in Fig.2 is used. It has a simple and an ease structure to implement, and requires only five parameters, hence, it is available in MATLAB/SIMULINK. The PV cell can be mathematically interpreted using Eq.1.

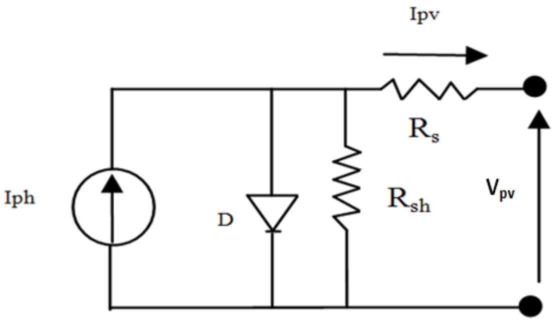

Figure 2: Single diode model solar cell

$$I_{pv} = I_{ph} - I_0.[\exp(\frac{(V_{pv} + I_{pv}.R_s)}{V_t a}) - 1] - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \qquad (1)$$

where:

I_{pv}: is the light current., I_0 :is the saturation current of the diode , a: represent the ideality factor, R_s and $R_{sh:}$ are the series and shunt resistances, respectively.

$$V_t = \frac{N_s kT}{q} \qquad (2)$$

V_a: denotes the thermal voltage. T is the temperature. q: represents the electron charge equals to $1.60217646.10^{-19}$C,k: presents the Boltzmann constant equals to $1.3806503.10^{-23}$ j/k,N_s: represents the number of series cells.

The interconnection of the photovoltaic panel to a variable resistive load allows us the draw of the Voltage-Current (V_{pv}-I_{pv}) and Voltage-Power (V_{pv}-P_{pv}) characteristics, which are of non-linear forms and affected by the changes of the irradiance and temperature. As illustrated in Fig.3**,** the increase in the irradiance level from 0.25KW/m², 0.5 KW/m², 0.75Kw/m² to 1KW/m² when maintaining the temperature at 25°C allows an increase in the I_{pv} and V_{pv}. So the power (P_{pv}) will increase too. In Fig.4, when preserving the irradiance level at 1kw/m², and varying the temperature value from 0°C, 25°C, 50°C,75°C to 100°C , the I_{pv} is not affected by this change, but the V_{pv} decreases at each increase on the temperature value leading to a reduction of the power generated.

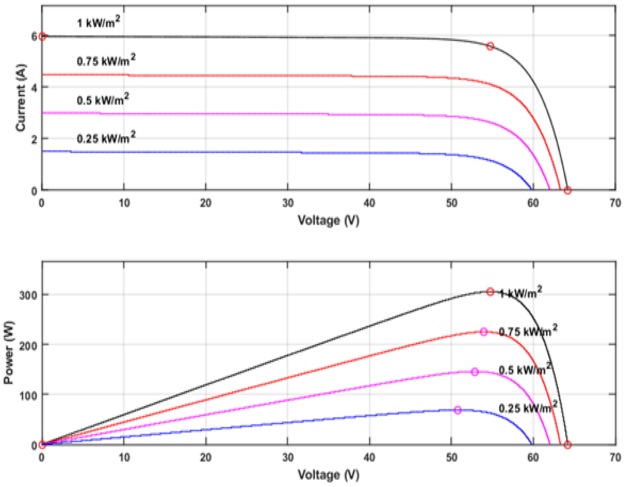

Figure 3: V_{PV}-I_{PV} and V_{PV}-P_{PV} characteristics. At 25°C

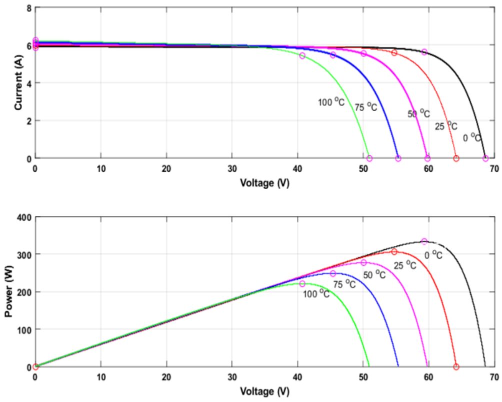

Fig.4. V_{PV}-I_{PV} and V_{PV}-P_{PV} characteristics. At 1KW/m²

The direct connection of the generator to the load is not secured and can lead to significant power loss. Moreover, it is impossible to control such weather conditions. So, to benefit from the solar photovoltaic energy, maximize the power generation, protect the system and match the harvested power with the load requirement, a boost converter with the characteristics listed in Table.1 is adapted and controlled through the two studied MPPTs techniques (fixed and Multi-Step incremental conductance) which will be detailed, simulated and compared in the following section.

Table.1. PV system Specifications

	Symbol	Parameter	Value
PV Module	P_{MPP}	Maximum power	305.2260W
	V_{MPP}	Voltage at Pmax	54.7V
	I_{MPP}	Current at Pmax	5.58A
	V_{OC}	Open-circuit-voltage	64.2 V
	I_{SC}	Short-circuit-current	5.96 A
DC-DC Boost Converter	C_{pv}	PV Capacitor	$100e_{-5}$ F
	L_b	Boost inductor	$1e^{-4}$ H
	C_b	Boost Capacitor	4900 µf
	f_S	Switching frequency	10 kHz
Load	V_L	Resistive Load	20 Ohm

B. Buck Converter

The circuit of the DC-DC boost converter illustrated in Fig.1 is controlled to step up the output voltage to load level. To fulfil the required voltage stability, the switching mechanism (ON/OFF) is essential. Both input voltage/output load conditions affect on the DC-DC boost converter, so, various control approaches have been developed and integrated to get MPP [3][14][18].

The dynamic model of this converter may be interpreted as:

$$\frac{dV_{pv}}{dt} = \frac{1}{C_{pv}} I_{pv} - \frac{1}{C_{pv}} I_L \qquad (3)$$

$$\frac{dI_L}{dt} = \frac{1}{L} V_{pv} - \frac{1}{L}(1-D)V_{dc} \qquad (4)$$

$$\frac{V_{dc}}{dt} = \frac{1}{C_{dc}}(1-D)I_L - \frac{1}{C_{dc}} I_{dc} \qquad (5)$$

The relationship between the input and output voltage expresses the duty ratio of the boost converter (D) as:

$$\frac{V_{dc}}{V_{pv}} = \frac{1}{1-D} \qquad (6)$$

$$\Delta q = \frac{\Delta I_L T_S}{8} \qquad (7)$$

III. PROPOSED CONTROLLERS

To extract the MPP and ensure an optimized generated power, the DC-DC boost converter is adapted to tune its input impedance through the generation of the PWM signal. This process is ensured via the MPPT techniques. As explained before, the incremental conductance technique outperforms the conventional P&O technique, so, it is adapted and more improvements are applied to its algorithm as detailed below:

A. Incremental Conductance with Fixed Setep Size

The Fig.5 gives the flowchart of the conventional Incremental conductance. The current and voltage of the PV panel are used as input of the algorithm to locate the MPP. The instantaneous conductance is equal to the negative of the incremental conductance at the MPP (Eq.9). This value is higher at the MPP left side and lower at the MPP right side as in Eq.10 and Eq.11 ,respectively [9][14].

It is necessary to note that the In-Cond is based on the slop of power variations which can be mathematically interpreted as in Eq.7.Where this variation is equal to zero at the MPP, less than zero at the left size and high than zero at the right side.

$$\frac{dP_{pv}(k)}{dV_{pv}(k)} = \frac{d(I_{pv}(k)\times V_{pv}(k))}{dV_{pv}(k)} = I_{pv}(k) + V_{pv}(k)\times\frac{dI_{pv}(k)}{dV_{pv}(k)} \approx I_{pv}(k) + V_{pv}(k)\times\frac{\Delta I_{pv}(k)}{\Delta V_{pv}(k)} \tag{7}$$

at the MPP:

$$\frac{dP_{pv}(k)}{dV_{pv}(k)} = 0 \tag{8}$$

So

$$\frac{I_{pv}(k)}{V_{pv}(k)} = -\frac{dI_{pv}(k)}{dV_{pv}(k)} \tag{9}$$

At the MPP left side:

$$\frac{I_{pv}(k)}{V_{pv}(k)} > -\frac{dI_{pv}(k)}{dV_{pv}(k)} \tag{10}$$

At the MPP right side:

$$\frac{I_{pv}(k)}{V_{pv}(k)} < -\frac{dI_{pv}(k)}{dV_{pv}(k)} \tag{11}$$

Compared to the conventional P&O MPPT technique incremental conductance can clearly eliminate the steady state oscillations. However, the transit state errors are similar in both techniques, especially during temperature and irradiance changes. Unfortunately, this will lead to noise and loss of the extracted power. So, less efficiency of the algorithm. In view of that, the present paper proposes and compared the following Multi step size In-Cond with the existing In-Cond which has a fixed step size.

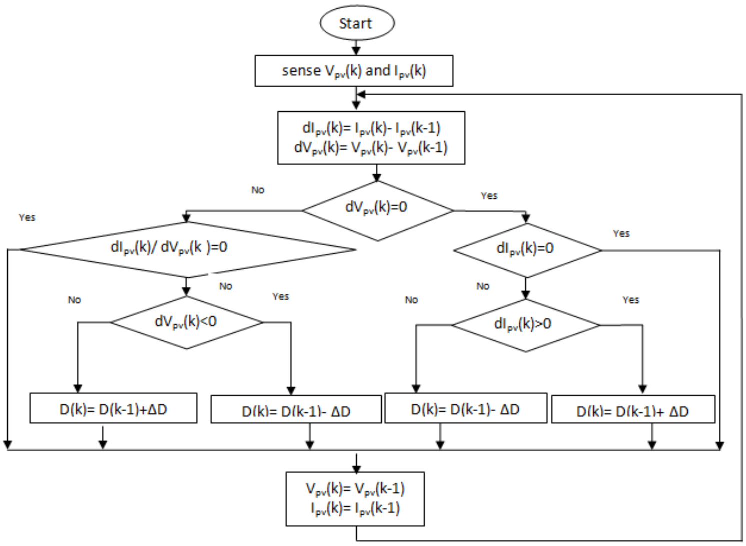

Figure 5: Incremental conductance with fixed step size

A. A Multi-step Size Inc-Cond

In the conventional incremental conductance one and fixed step size is considered to get the MPP value. This step size affects the rapidity and stability of the system. Indeed, a small value will slow the system and a large value causes oscillations around the MPP. To deal with this problem, the present work focuses on selecting multistep size $\Delta D_1=0.005$, $\Delta D_2=0.0005$, by improving the research mechanism of the existing incremental conductance., then, designing the duty ratio of the boost converter according to the load voltage requirement. In fact, the proposed algorithm has the same procedure as the conventional Inc-Cond, the only difference is that two steps size are considered instead of using a fixed value. This process is repeated until stabilizing at the MPP value. The flowchart of this algorithm is drawn in Fig.6. It is clear from Fig.6 that a large duty cycle variation (ΔD_1) is added to the output duty cycle when the condition of Eq.12. is satisfied, in this case , mains that the operating point is far from the MPP and we must design a large variation value to reach the MPP.

$$\Delta P_{PV}(k) < 0.85 \times P_{\max} \qquad (12)$$

In another hand, if this variation is small Eq.13. is satisfied the designed $\Delta D_2 = 0.0005$, mains that the operating point approaches the MPP. So, to avoid the stability problems, high power ripples and ameliorates the performance of the system a small value of the duty cycle variation must be selected and added to the duty cycle.

$$\Delta P_{PV}(k) \geq 0.85 \times P_{\max} \qquad (13)$$

Then the duty cycle is either incremented or decremented by those variations following the same process as the existing Incremental Conductance explained in the previous part of this section.

The procedure of the research mechanism is repeated until achieving the MPP.

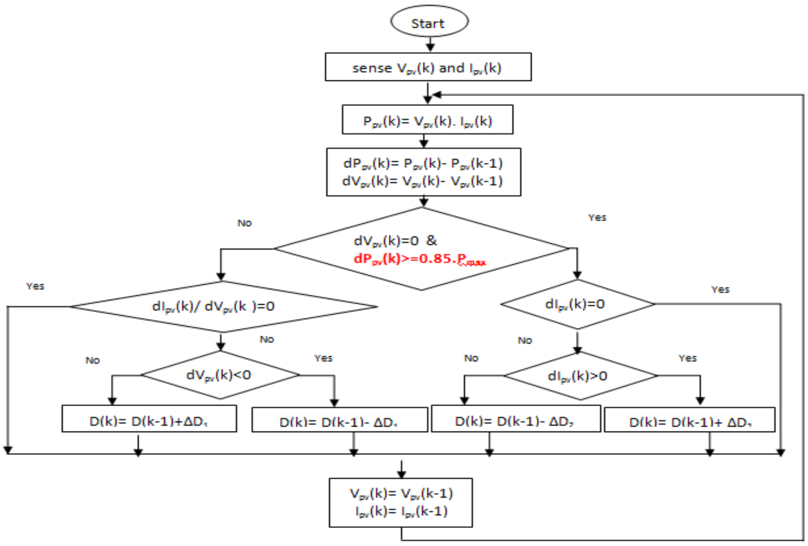

Fig.6. Flowchart of the proposed variable step-size Inc-Cond

IV. SIMULATION RESULTS AND DISCUSSIONS

The simulation has been carried out through Simulink using the system of Fig.1. A SunPower SPR-305-WHT PV module is used. Its specifications and the parameters of the boost converter and load are listed in Table 1. The system is first simulated under Standard Test Conditions (STC) of irradiance level and temperature value which are 1KW/m² and 25°C, respectively. Besides, a real sun curve and variable change in irradiance are also applied to test and analyze the dynamic and static response, study the efficiency of the proposed Multi-Step size inc-Cond compared to the existing incremental conductance technique.

A. Under Standard Test Conditions (STC)

PV Power extracted using Both algorithms under STC (25°C-1KW/m²) is depicted in Fig.7.bellow. Compared to conventional Inc-Cond, the proposed MSS-In-Cond is able to mitigate the power ripples and loss in steady state and transit response. Two different duty cycle variations values are used to simulate the Inc-Cond (dD=0.005 and dD=0.0005). These values are also adapted in the improved MSS-Inc-Cond. Clearly, when a small step size is affected to the conventional Inc-Cond (dD=0.005), the response time is around 0.025s. When affecting a large step size the same response time of 0.015s is obtained using both techniques. but, at steady state, it is clear from the Power curves that the conventional Inc-Cond shows high ripples compared to the proposed technique. Because the proposed technique is capable of designing small step size when approaching the MPP and large value far from the MPP. It can be noted that the proposed technique has a high response time at STC, with an efficiency of 98.4% , 98.02% and 97.98% using the proposed technique, conventional Inc-Cond with dD=0.0005, conventional Inc-Cond with dD=0.005 ,respectively.

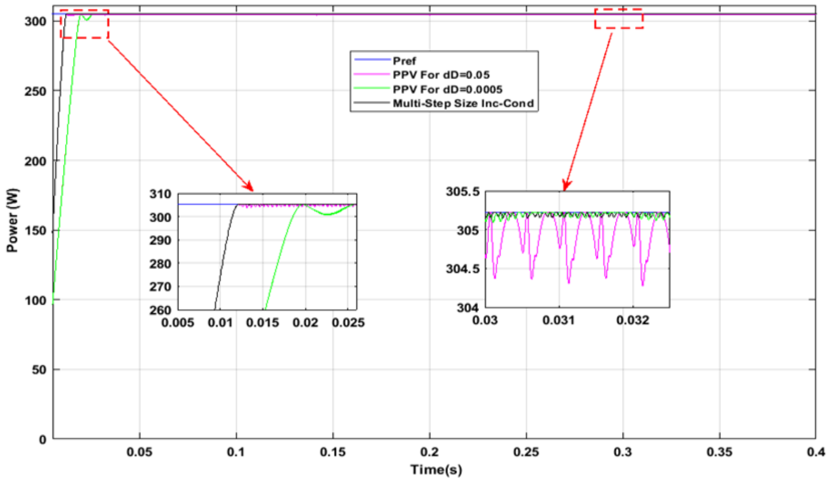

Fig.7. Power using both algorithms at STC

B. Under Variable Irradiance Level

Under an instantaneous change in weather conditions when the irradiance decreases from 1kw/m² to 0Kw/m² taking an irradiance variation of 0.1KW/m². The simulation of the conventional and the proposed techniques are drawn in the same figure to compare their behaviour as depicted in the curves of the Fig.8.the conventional algorithm shows a response time of around 0.3s at each step of irradiance (from 1KW/m² to 0.6Kw/m²) compared to 0.043s when using the proposed strategy. this means that the tracking speed rises through the use of the MSS-Inc-Cond of about 10%. the output Power loss of the PV module is about 1 W compared to 3W using the proposed and the conventional technique, respectively. It can be noted that at small irradiance level, the proposed technique has the same curve with the conventional technique in term of loss and response time. So, it can be effectively used in high irradiance level to surmount the drawbacks of the conventional technique with fixed step size.

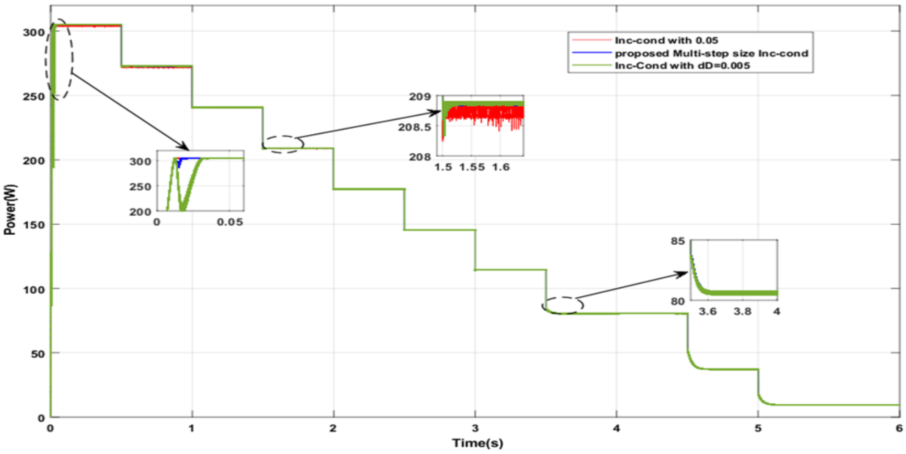

Figure 8: Power curve of the simulated MPPTS under Variable Irradiance Level

C. Under Real Sun Curve

Under real sun trajectory curve, which is equal to zero in the begging and the end of the day(Fig.9.). Then the power rises and forms a non-linear curve as depicted in figure bellow:

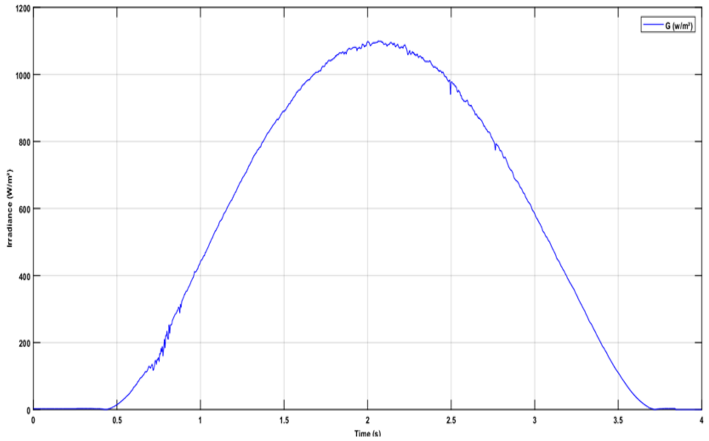

Figure 9: Irradiance applied following the sun trajectory curve

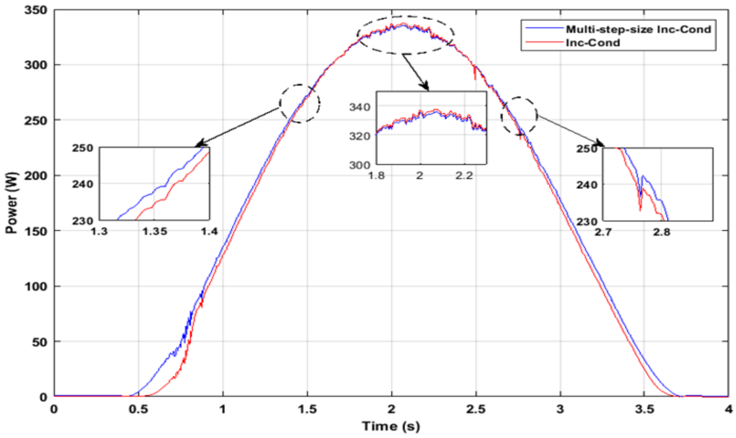

Figure 10: Power harvested using real sun curve

The powers harvested using both algorithms are drawn in Fig.10. Analysing the results, we can clearly notice that the proposed technique stays outperforming the traditional Inc-Cond in response time and harvested power. Except when the irradiance level is higher than 1Kw/m². As indicated in the zoom-in of fig.*10.*

From the discussions above, it will be concluded that the proposed technique will with success manage both uniform insulation and quick varied insulation level, by varying the duty cycle using the adequate step size values. Additionally, the projected technique is ready to find the precise MPP and stabilize the dc voltage delivered to the load.

V. CONCLUSION

In this paper, a multi step size incremental conductance based MPPT for a PV system is implemented using MATLAB/Simulink, and compared to the Conventional Incremental conductance which uses a fixed step size.

A detail design of the PV system is done. In fact, a single PV cell configuration is considered, then, details about the components and controllers used are given before simulating the proposed MSS-Inc-Cond and comparing its behaviours with the Conventional Incremental conductance which uses a fixed step size.

From the given simulations results, it can clearly concluded that proposed technique can reach MPP with low steady state and react instantaneously to the changes appearing during its operating process. The variable step size technique shows improved efficiency and batter behaviour compared to conventional In-Cond.

In the future work, the proposed MSS-Inc-Cond will be improved and validated under partial shading conditions, for standalone and grid connected PV system. Moreover, the inclusion of storage devices and others energy sources such as wind turbines and fuel cells will be considered.

Besides, others power quality and stability problems will be studied to offer flexible and systems with exploitable behaviour. Furthermore, the improvement of power electronic interfaces will take a part of our future contributions.

REFERENCES

[1] Singh O & Gupta SK. (2018). A review on recent Mppt techniques for photovoltaic system. *IEEMA Engineer Infinite Conference (eTechNxT)*, pp. 1-6.

[2] ndib B, Belmili H & Krim F. A (2015 May). Survey of the most used MPPT methods: Conventional and advanced algorithms applied for photovoltaic systems. *Renewable and Sustainable Energy Reviews, 1*(45), 637-48.

[3] Taghvaee MH, Radzi MA, Moosavain SM, Hizam H & Marhaban MH. (2013 Jan). A current and future study on non-isolated DC–DC converters for photovoltaic applications. *Renewable and sustainable energy reviews, 1*(17), 216-27.

[4] Ge B, Peng FZ & Li Y. (2015). Multilevel converter/inverter topologies and applications. *Power Electronics for Renewable Energy Systems, Transportation and Industrial Applications, 18*, 422-62.

[5] Hamidon FZ, Aziz PA & Yunus NM. (2012 Sep). Photovoltaic array modelling with P&O MPPT algorithm in MATLAB. *International Conference on Statistics in Science, Business and Engineering (ICSSBE)*, pp. 1-5.

[6] Putri RI, Wibowo S & Rifa'i M. (2015). Maximum power point tracking for photovoltaic using incremental conductance method. *Energy Procedia, 68*, 22-30.

[7] Mahmoud, A.M.A., Mashaly, H.M., Kandil, S.A., El Khashab, H. & Nashed, M.N.F. (2000, Oct). Fuzzy logic implementation for photovoltaic maximum power tracking. In: *26th Annual Conference of the IEEE Industrial Electronics Society. IECON 2000. 2000 IEEE International Conference on Industrial Electronics, Control and Instrumentation. 21st Century Technologies, 1*, pp. 735-740.

[8] Jie L & Ziran C. (2011). Research on the MPPT algorithms of photovoltaic system based on PV neural network. In: *Chinese Control and Decision Conference (CCDC)*, pp. 1851-1854.

[9] Rahman MW, Bathina C, Karthikeyan V & Prasanth R. (2016) Comparative analysis of developed incremental conductance (IC) and perturb & observe (P&O) MPPT algorithm for photovoltaic applications. In: *10th International Conference on Intelligent Systems and Control (ISCO)*, pp. 1-6.

[10] F. Liu, S. Duan, F. Liu, B. Liu & Y. Kang. (2008). A variable step size INC MPPT method for PV systems. In: *IEEE Transactions on Industrial Electronics, 55*(7), 2622-2628. DOI: 10.1109/TIE.2008.920550.

[11] Zakzouk, N. E., Williams, B. W., Helal, A. A., Elsaharty, M. A. & Abdelsalam, A. K. (2016). Improved performance low-cost incremental conductance PV MPPT technique. *IET Renewable Power Generation, 10*(4), 561–574. DOI: 10.1049/iet-rpg.2015.0203.

[12] Mei Q, Shan M, Liu L & Guerrero JM. (2010). A novel improved variable step-size incremental-resistance MPPT method for PV systems. *IEEE Transactions on Industrial Electronics, 58*(6), pp. 2427-34.

[13] Ahmed EM & Shoyama M. (2011). Stability study of variable step size incremental conductance/impedance MPPT for PV systems. In: *8th International Conference on Power Electronics-ECCE Asia 2011*, pp. 386-392.

[14] Yasmine A, Rafik B, Rachid B & Adel M. (2020). Grid connected photovoltaic system efficiency and quality improvement using fuzzy-incond MPPT. *International Journal of Power Electronics and Drive Systems, 11*(3), 1536.

[15] Punitha K, Devaraj D & Sakthivel S. (2013). Artificial neural network based modified incremental conductance algorithm for maximum power point tracking in photovoltaic system under partial shading conditions. *Energy, 62*, 330-40.

[16] S. Z. Mirbagheri, M. Aldeen & S. Saha. (2015). A PSO-based MPPT re-initialised by incremental conductance method for a standalone PV system. *23rd Mediterranean Conference on Control and Automation (MED), Torremolinos*, pp. 298-303. DOI: 10.1109/MED.2015.7158766.

[17] Amara Y, Boukenoui R, Bradai R & Salhi H. (2018). Design and control of two-stage standalone photovoltaic generation system. In: *International Conference on Communications and Electrical Engineering (ICCEE)*, pp. 1-5.

[18] Yasmine, A., Rafik, B., Rachid, B. & Adel, M. (2020). Management of hybrid pv/battery stand-alone system under partial shading conditions. In: *1st International Conference on Communications, Control Systems and Signal Processing (CCSSP)*, pp. 429-434.