A New Technique for Photovoltaic System Efficiency under Fast Changing Solar Irradiation

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Abstract

Maximum power point tracking (MPPT) techniques play an important role in efficiency improvement of photovoltaic systems. But, the fast variation of solar irradiation affects the work of these techniques, which degrades the efficiency of these systems. To treat this problem, the present paper proposes a simple MPPT algorithm based on developing a formula for calculating the duty cycle of the converter. This method is based on the verity that the power slope of the PV is null at MPP. This technique consists on an improved INC algorithm, which is used to avoid the poor tracking of the MPP under fast changing irradiance and the high-power oscillation in steady state.
The proposed method is verified and simulated. The simulation showed that the response of the proposed algorithm only needs 22% of the time taken by the conventional incremental conductance algorithm to track the maximum power point (MPP) during solar irradiation variation. In addition, the proposed technique shows a negligent oscillation in the power generated after tracking the maximum power point (MPP).

Keywords: Photovoltaic system; MPPT; incremental conductance, boost converter, fast convergence

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1. Introduction

The rapid depletion of global fossil fuel resources has necessitated urgent research for renewable energy sources. Among the many alternatives, photovoltaic has been considered promising to meet the growing demand for energy. The photovoltaic power source is inexhaustible, the conversion process is pollution-free, and its availability is free [1] - [3]. However, the power generated by the PV system is unstable and highly dependent on solar irradiation. This is why the MPPT controller, which follows the maximum power point, is used to ensure that the PV system always has a high efficiency despite the variation of the solar irradiation [4], [5].

To increase the efficiency of the PV system, several MPPT algorithms have been used. Among them are fractional short-circuit current, fractional open circuit voltage [6], [7], fuzzy logic [8], [9], neural network [7]-[10], hill climbing [11], [12] or perturbation and observation (P&O) [9], [13], [14], and incremental conductance [6], [12], [15]. The most popular one is the incremental conductance algorithm. It is widely used in PV system products to extract MPP because of its simplicity, ease of implementation and low cost. The basic flowchart of the incremental conductance algorithm is presented in Figure 1.

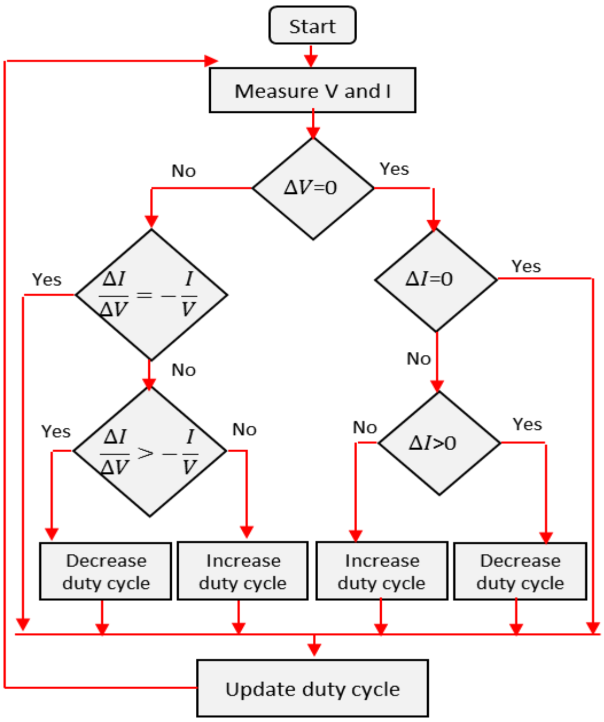

Figure1. Flowchart of the incremental conductance algorithm

In this technique, MPP can be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance ($\frac{dI}{dV}$). If the operating power point is on the left side of the MPP, the algorithm must move it to the right to be nearer to the MPP, and vice versa if it is on the opposite side (on the right side) [16] - [19].

However, the major problems of the incremental conductance method are the poor tracking of the MPP under fast changing irradiance and the high-power oscillation in steady state. In this context, different modified incremental conductance algorithms have been documented to solve these issues. To maximize the power of a PV system for rapidly changing weather Conditions, a modified INC algorithm is suggested by Soon and Mekhilef [20]. This method based on the relationship between the load line and the I-V curve is used with trigonometry rule to ensure the fast response. This algorithm reduced the oscillation in steady state by using a permitted error for the difference in power (dP). To avoids divergence in the case of a sudden increase in irradiance level a modified INC algorithm has been reported by Belkaid, Colak and Isik [21]. This technique proposed a changing the direction of the perturbation of the duty cycle in case of sudden varying atmospheric conditions. An improved INC algorithm has been reported by Motahhir, El Ghzizal, Sebti, and Derouich [22]. This method checks if both voltage and current are increased; in this case, the duty cycle is increased instead of decreased as made by the conventional algorithm. Hence, the INC algorithm is modified to avoid the wrong decision made by the conventional algorithm. A variable step size INC algorithm has been reported by Isaloo and Amiri [23]. In this method a variable step size algorithm which is based on the incremental conductance technique is suggested to regulate the step size using the slope of power voltage curves of PV system and also to modify step size correspond to sun irradiation levels. A modified incremental conductance MPPT algorithm based on a fuzzy logic is suggested by Radjai, Rahmani, Mekhilef and Gaubert [24]. To avoid the inefficiency of the conventional IC algorithm, a new IC controller based on a fuzzy duty cycle change estimator is developed. The new duty cycle is estimated using a fuzzy logic estimator (FLE).

In this article the proposed algorithm does not require an additional control loop. The proposed system is based on a dc-dc converter that is placed between the PV module and the load. The structure of the proposed system is shown in Figure 2.

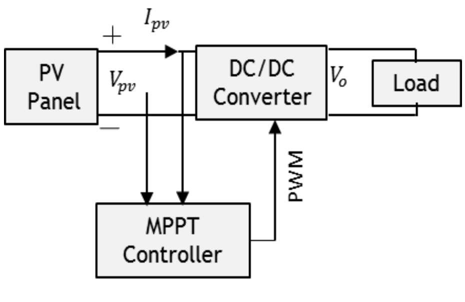

Figure2. Proposed PV system with MPPT technique

To detect the variation of the level of solar radiation, this algorithm controls the direction of the variation of the current (dI) and voltage (dV). A common decrease the current and the voltage means a decrease in solar radiation. On the other hand, a common increase means an increase in solar radiation.

The proposed technique makes it possible to calculate a value of the cyclic ratio of the DC-DC converter very close to that of the new maximum power point (MPP), using the developed equations. A few more steps of conventional incremental conductance algorithm are used to reach the new MPP. To minimize the oscillation of the power, a small error is accepted for (dP). The simulation results show the good performance of the suggested algorithm in terms of convergence speed or oscillation.

2. Modelling of PV system

A. Modelling of a photovoltaic cell

PV module comprises an Assembly of solar cells connected in parallel or series. To understand solar cell work, few types of models have been developed, such as single- diode and double diode model [25-28], [29]. In this paper, we used a simplified model of single-diode.

This model comprises a current source, a diode, and parasitic resistors. the resistive properties of the cell are presented by a series resistance R_s and leak currents are presented by a parallel resistance R_p [2], [30-32].

The equation which links the current supplied by a module composed of N_s PV cells and the voltage at its terminals is given by equation (1) [4], [32–35].

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_s}\left[\exp\left(\frac{\mathrm{q.(V+I.R_S.N_S)}}{\mathrm{n.k.T_C.N_S}}\right) - 1\right] - \frac{\mathrm{V+I.R_S}}{\mathrm{R_p}} \quad (1)$$

where: I is the output current of PV module, V is the output voltage of PV module, I_{ph} is the photo-current, I_s is the saturation current, q the electron charge, n the diode ideality factor, k the Boltzmann constant, T_c junction temperature.

The parallel resistance R_p is normally very large and can be considered as an open circuit [28].

The expression $\exp\left(\frac{\mathrm{q.(V+I.R_S.N_S)}}{\mathrm{n.k.T_C.N_S}}\right) \gg 1$, so the equation current-voltage of the module can be rewritten as:

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_s}\left[\exp\left(\frac{\mathrm{q.(V+I.R_S.N_S)}}{\mathrm{n.k.T_C.N_S}}\right)\right] \quad (2)$$

The reverse saturation current or leakage current of the diode I_s is shown as follows:

$$\mathrm{I_s} = \frac{\mathrm{I_{ph}}}{\exp\left(\frac{\mathrm{q.(V_{OC})}}{\mathrm{n.k.T_C.N_S}}\right)} \quad (3)$$

where: V_{oc} is the open circuit voltage of PV module.

The photo-current I_{ph} is the current value generated where V = 0, $\mathrm{I_{ph}} \approx I_{sc}$.

where: I_{sc} is the short circuit current of the PV module

So (1) can be simplified as follows:

$$\mathrm{I} = I_{sc}\left[1 - \exp\left(\frac{\mathrm{V - V_{oc} + I.N_S.R_S}}{\mathrm{N_S.V_{th}}}\right)\right] \quad (4)$$

where: $V_{th} = \mathrm{n.k.}\frac{\mathrm{T_c}}{\mathrm{q}}$

B. Modelling of DC-DC Converter

The DC-DC converter used in this research is a boost Converter. This converter comprises A inductor, a capacitor, a diode and a switch.

The switch is controlled by a signal of period T and duty cycle D [7], [36], [37].

The relationships of the voltage and current of the dc-dc converter between the input and output sides are shown in (5) and (6). These equations are specifically required for boost Converter which operates in continuous-conduction mode and may be different for other types of converter [37-41].

$$V_i = (1-D)V_o \tag{5}$$

$$I_i = I_o/(1-D) \tag{6}$$

Equation (7) is obtained by dividing (5) by (6):

$$R_i = (1-D)^2 R_o \tag{7}$$

where V_i the voltage of the photovoltaic generator is, I_i is the current of the photovoltaic generator. V_o the output voltage of the converter or the load voltage, I_o the output current of the converter or the load current. R_i is the resistance seen by the PV generator, and R_o is the load resistance.

3. Proposed algorithm

The proposed algorithm adopts the basis of the incremental conductance method: the power slope of PV is null at MPP ($\frac{dP}{dV}=0$). This equality means that $\left(\frac{dI}{dV}=-\frac{I_{mpp}}{V_{mpp}}\right)$. With compensation of the formula of current I_{pv} as a function of voltage V_{pv} in the derivative $\left(\frac{dI}{dV}\right)$, a relationship between I_{mpp} and V_{mpp} is found. From this relation, the value of the resistance seen by the PV module or the input resistance of the converter R_{in} can be calculated. The calculation of the input resistance of the converter makes it possible to calculate an approximate value of Duty cycle of the converter very close to that of point MPP. This algorithm only needs the current and voltage values to do the calculation that converges quickly to the MPP point.

The power slope of the PV is null at MPP. This rule can be presented by (8).

$$I_{mpp} + V_{mpp}\frac{dI}{dV} = 0 \tag{8}$$

Equation (8) is rearranged to obtain (9)

$$\frac{dI}{dV} = -\frac{I_{mpp}}{V_{mpp}} \tag{9}$$

By deriving the equation (4) we obtain the equation (10)

$$\frac{dI}{dV} = -I_{sc}.\frac{\left(1+\mathrm{N_s.R_s}\frac{dI}{dV}\right)}{N_s.V_{th}} exp\left(\frac{V-V_{oc}+I.\mathrm{N_s.R_s}}{N_s.V_{th}}\right) \tag{10}$$

Equation (4) can be rewritten as follows;

$$exp\left(\frac{V-V_{oc}+I.\mathrm{N_s.R_s}}{N_s.V_{th}}\right) = 1-\frac{I}{I_{sc}} \tag{11}$$

The equations (10) and (11) used to obtain Equation (12)

$$\frac{dI}{dV} = -I_{sc}.\frac{\left(1+\mathrm{N_s.R_s}\frac{dI}{dV}\right)}{N_s.V_{th}}\left(1-\frac{I}{I_{sc}}\right) \tag{12}$$

At the maximum power point (MPP) The equation (12) can be rewritten as follows:

$$\frac{I_{mpp}}{V_{mpp}} = I_{sc}.\frac{\left(1-\mathrm{N_s.R_s}\frac{I_{mpp}}{V_{mpp}}\right)}{N_s.V_{th}}\left(1-\frac{I_{mpp}}{I_{sc}}\right) \tag{13}$$

Equation (13) is then simplified to obtain (14) as follows:

$$N_s.V_{th}.I_{mpp} = V_{mpp}.I_{sc} - V_{mpp}.I_{mpp} - \mathrm{N_s.R_s}.I_{mpp}.I_{sc} + \mathrm{N_s.R_s}.{I_{mpp}}^2 \tag{14}$$

(14) is multiplied by ${R_{in}}^2$ and simplified to obtain (15), where $R_{in}$is the input resistance of the converter or the resistance seen by the PV module.

$$I_{sc}.{R_{in}}^2 - \left(V_{mpp} + I_{sc}.\mathrm{N_s.R_s} + N_s.V_{th}\right).R_{in} + \mathrm{N_s.R_s}.V_{mpp} = 0 \tag{15}$$

The calculation of parameter of equation (15) :

In (7), R_{in} is substituted by $\frac{V_{pv}}{I_{pv}}$. The load resistance can be calculated as follows:

$$R_{out} = \frac{V_{pv}}{I_{pv}.(1-D)^2} \tag{16}$$

The value of $\mathrm{N_s.R_s}$ can be calculated using (4) by substituting the voltage, and current at the maximum power point (MPP).

$$I_{mpp} = I_{sc}\left[1-exp\left(\frac{V_{mpp}-V_{oc}+\mathrm{I_{mpp}.N_s.R_s}}{N_s.V_{th}}\right)\right] \tag{17}$$

(17) can be rewritten as:

$$\mathrm{N_s.R_s} = \frac{N_s.V_{th}.ln\left(1-\frac{I_{mpp}}{I_{sc}}\right)+V_{oc}-V_{mpp}}{I_{mpp}} \tag{18}$$

The short circuit current is always approximately $1.1 * I_{mpp}$ and the approximated open circuit voltage is obtained from $1.25 * V_{mpp}$.

The expression of $\mathrm{N_s.R_s}$ is substituted into (14) to obtain equation (19).

$$N_s.V_{th}.I_{mpp} = V_{mpp}.I_{sc} - V_{mpp}.I_{mpp} + \frac{N_s.V_{th}.ln\left(1-\frac{I_{mpp}}{I_{sc}}\right)+V_{oc}-V_{mpp}}{I_{mpp}}.\left(-I_{mpp}.I_{sc}+{I_{mpp}}^2\right) \tag{19}$$

The approximated value of $N_s.V_{th}$ is calculated as follows:

$$N_s.V_{th} = \frac{(I_{sc}-I_{mpp})+(2V_{mpp}-V_{oc})}{I_{mpp}+(I_{sc}-I_{mpp})ln\left(1-\frac{I_{mpp}}{I_{sc}}\right)} \tag{20}$$

To ensure the PV module operates near to the new MPP R_{in} can be calculated as follows:

$$\begin{cases} R_{in1} = \frac{-b+\sqrt{b^2-4.a.c}}{2a} \\ R_{in2} = \frac{-b-\sqrt{b^2-4.a.c}}{2a} \end{cases} \tag{21}$$

where: $a = I_{sc}$, $b = -\left(V_{mpp} + I_{sc}.\mathrm{N_s.R_s} + N_s.V_{th}\right)$ and $\mathrm{c} = \mathrm{N_s.R_s}.V_{mpp}$.

As shown in Figure 3, in case of an increase in solar irradiation, the new short circuit current is calculated approximately by applying the trigonometry rule as follows:

$$I_{sc} = I_{pv_{new}} . \frac{V_{oc} - V_{mpp}}{V_{oc} - V_{pv_{new}}} \quad (22)$$

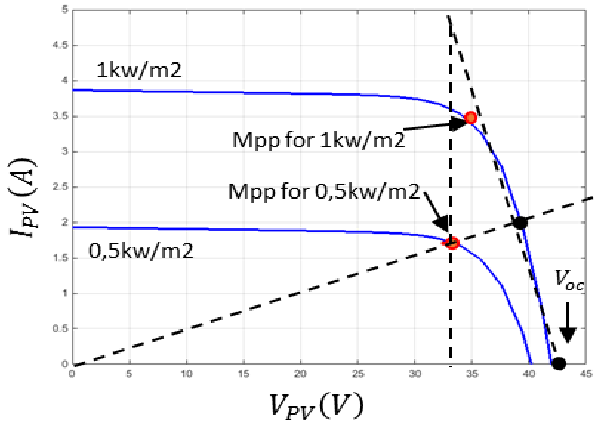

Figure 3. Load lines on *I-V* curves for solar irradiation level of 0.5and 1.0 kW/m2 during increase of solar irradiation

In case of a decrease in solar irradiation, the new short circuit current is approximately as follows:

$$I_{sc} = I_{pv_{new}} . (1 + 0.1(I_{pv_{new}}/I_{mpp})) \quad (23)$$

Accepted the values of R_{in} who to chek (7), that is to say $0 \leq R_{in} \leq R_{out}$

The value of R_{in} is substituted in (7) to calculate the duty cycle D as follows:

$$D = 1 - \sqrt{\frac{R_{in}}{R_{out}}} \quad (24)$$

Figure 4 shows the different steps of the proposed algorithm.

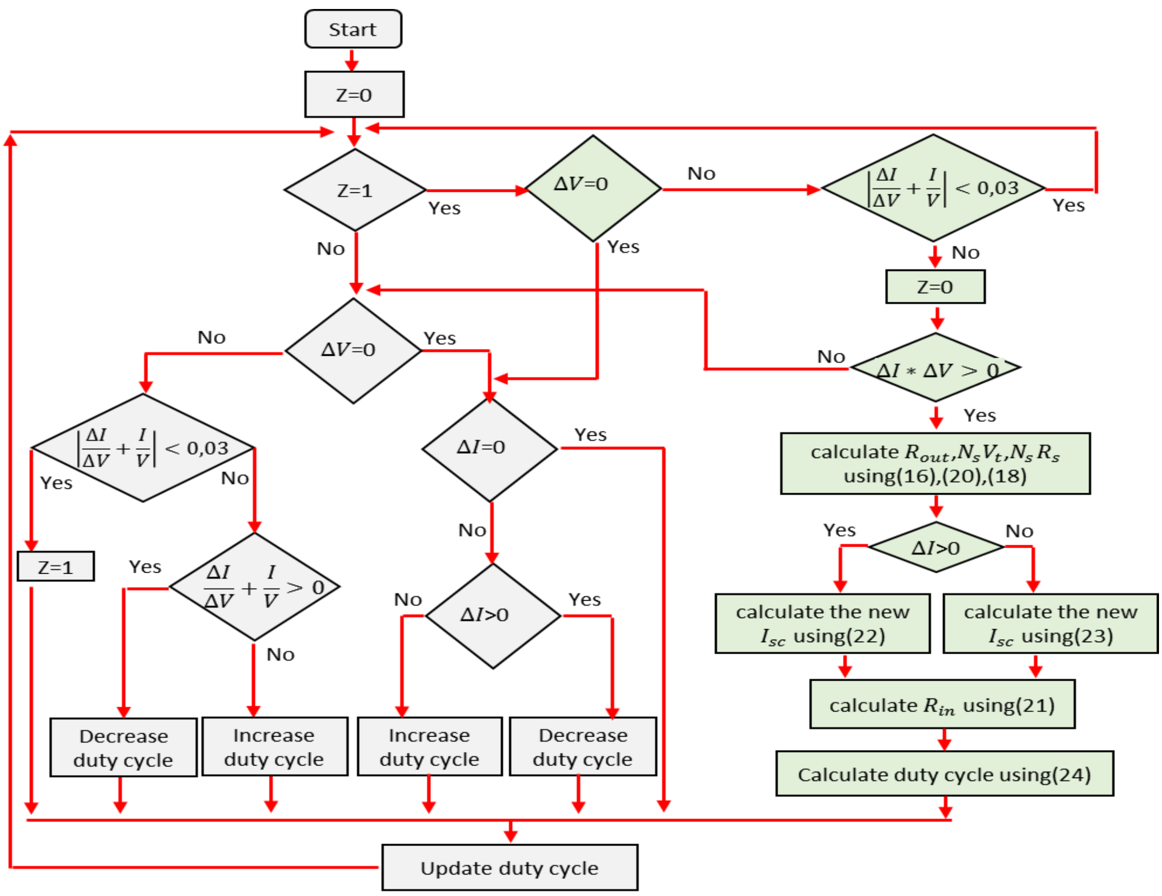

Figure 4. The different steps of the suggested algorithm

A permitted error of 0.03 as shown in (25), is used in the proposed algorithm to eliminate the steady-state oscillation in the system after the MPP is reached.

$$\left|\frac{I}{V} + \frac{dI}{dV}\right| < 0.03 \quad (25)$$

In this algorithm, the variation of solar irradiation is detected by increase or decrease both the voltage and current of PV module simultaneously. That is to say $dI.dV > 0$. If this condition is verified, (20) is used to calculated $N_s.V_{th}$. Then, the value of $N_s.V_{th}$ is substituted into (18) to calculated $N_s.R_s$.

After that, the new value of I_{sc} is calculated by using (22) in case of increase of solar irradiation, or by using (23) in case of decrease of solar irradiation. Therefore, R_{in} can be calculated by using (21). Then R_{in} and R_{out} are substituted into (24) to obtain the new duty cycle.

After any variation of the solar irradiation, the new duty cycle is calculated. Until the difference in power (dP) is smaller than 0.03.

4.Simulation results

To test the performance of the proposed algorithm, it is verified by numerical simulation and compared with other MPPT algorithms. The chosen photovoltaic generator is a module of (PB solar BP sx120) of 120 Wp.

Table 1 shows the parameters of the PV module under standard conditions (STC) and the values of the converter elements.

Table 1. Parameters of the PV modules and the boost converter

PV array	Values (STC)
Open circuit voltage (V_{oc})	42.1 V
Optimum operating voltage (V_{mpp})	33.7 V
Short circuit current (I_{sc})	3.87 A
Optimum operating current (I_{mpp})	3.56 A
Maximum power (P_{mpp})	120 W
Temperature coefficient of (V_{oc})	-0.16 V/°C
Temperature coefficient of (I_{sc})	0.065 %/°C
Boost converter	Nominal values
Inductance(L)	7.5 mH
Capacitance (C_{in})	330 µF
Capacitance (C_{out})	200 µF
Load resistive (R)	50 Ω

The sampling time by the algorithms MPPT, is 1ms. The temperature is taken 25 °C. The profile of solar irradiation applied to the MPPT algorithms, is given in Figure 5.

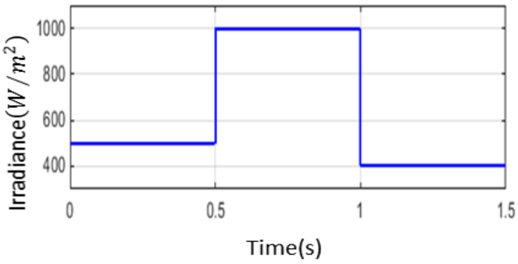

Figure 5. Solar irradiance profile

The dynamic responses for the power outputs of the PV generator for the various simulated algorithms are shown in Figure 6.

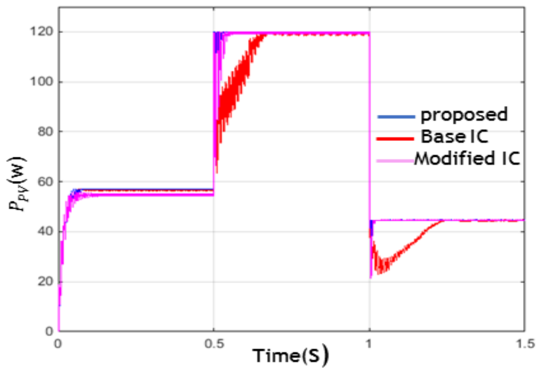

Figure 6. PV output power waveforms for different MPPT algorithms

Solar irradiation takes the level of 500 W/m² at the beginning. Then, the algorithms tracked the MPP and the proposed MPPT shows a better performance in terms of power fluctuation with a power oscillation less than at 0.116 W (57.06-57.176 W). When the modified incremental conductance algorithm developed by Soon and Mekhilef finds the MPP with power oscillation (54.3 -55.16 w).

For the conventional incremental conductance, the PV power is fluctuating around MPP (56.26-57.19 W). Then solar irradiation increases rapidly from 500w / m² to 1000 W/m² at t = 0.5 s, among the simulated techniques, the suggested method presents a better performance in terms of the speed of the achievement of MPP and oscillation, as shown in Figure 7.

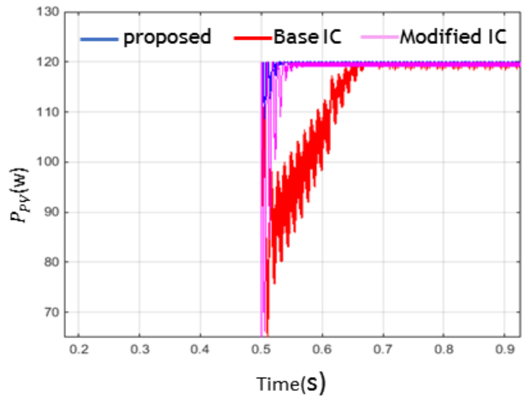

Figure 7. Zoom-in view of power waveforms during increase in solar irradiation

When the proposed algorithm takes only 0.017 s to reach the MPP with fluctuation of the steady-state PV power less than 0.36 W (119.632-119.987 W) as illustrated in Figure 8.

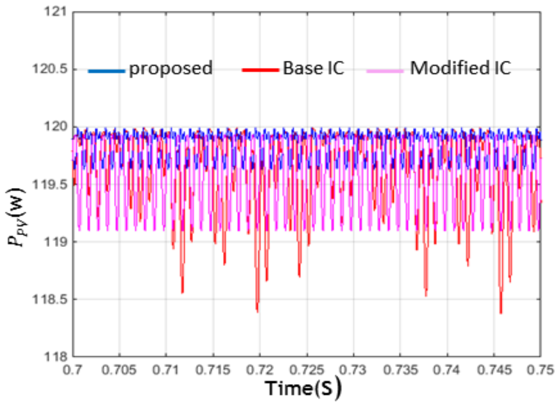

Figure 8. Zoom-in view of power waveforms after the MPP is reached

Whilst for the modified incremental conductance method it takes 0.045 s (more two times than the proposed MPPT) to follow the MPP with an oscillation power equal to 0.833 W (119.097-119.93 W).

For the conventional incremental conductance algorithm, it takes 0.16 s to follow the MPP with a significant power swing 1.7 W (118.378-119.99 W). Finally, a sudden decrease in solar irradiance at t=1s, from 1000 W/m^2 to 400 W/m^2.

Therefore, the proposed method works better than the modified incremental conductance algorithm and the conventional incremental conductance algorithm, with neglected steady state PV power oscillation, and the MPP is directly achieved despite the sudden change in the level of irradiance as presented in Figure 6.

The average time to monitor the proposed algorithm during a sudden change in irradiance is 0.0095 s, but with the classical incremental conductance algorithm, it takes 0.245 s and the modified incremental conductance requires 0.012 s. A comparison table presenting the main values obtained in simulation for different MPPT is presented in Table 2.

Table 2. Summary of simulation results

Technique	Step change in irradiance 500 → 1000 W/m^2		Step change in irradiance 1000 → 400 W/m^2	
	Tracking speed time (s)	Power oscillation (W)	Tracking speed time (s)	Power oscillation (W)
INC	0.16	1.612	0.245	0.639
modified IC[S.M]	0.045	0.833	0.012	0.08
Proposed MPPT	0.017	0.354	0.0095	0.08

5. Conclusion

This paper presents design and simulation of a MPPT control for the PV stand-alone system by using advanced control strategy. The proposed technique has been successfully simulated. Simulation results proved that the proposed algorithm has enhanced the PV system performance compared to the modified incremental conductance algorithm and the conventional incremental conductance algorithm. The results show that the proposed algorithm detects the fast increase and decrease of solar irradiation and makes an accurate decision compared to the other techniques. Moreover, by using the proposed technique, steady-state oscillations in the system are almost neglected. which reduces power losses. As a conclusion, a fast converging and low losses MPPT algorithm is proposed and verified in this paper.

6. Bibliographic references

[1] M. A. Abdullah *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **184** 012020. M. A. Abdullah *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **184** 012020

[2] De Leone, R., Pietrini, M., Giovannelli, A., "Photovoltaic energy production forecast using support vector regression", in: *Neural Comput. Appl.*, 2015, vol. 26,issue 8, pp. 1955-1962.

[3] ABOUADANE, H., FAKKAR, A., ELKOUARI, Y., OUOBA, D., "Performance of a new MPPT method for Photovoltaic systems under dynamic solar irradiation profiles ", in: Energy Procedia, 2017, vol. 142, pp. 538-544.

[4] Sree Manju, B., Ramaprabha, R., Mathur, B., "Design and Modelling of Standalone Solar Photovoltaic Charging System," in: *International Journal of Computer Applications*, 2011, vol. 18, no. 2, pp. 41-45.

[5] Eltamaly, A.M, Farh, H.M.H., Othman, M.F., "A novel evaluation index for the photovoltaic maximum power point tracker techniques", in: Solar Energy,2018, vol. 174, pp. 940-956.

[6] Subudhi, B., Pradhan, R., "A comparative study on maximum power point tracking techniques for photovoltaic power systems", in: IEEE Trans. Sustainable Energy, 2013, vol. 4, no. 89.

[7] Liu, Y.H., Liu, C.-L., Huang, J.W., Chen, J.H., "Neural-network-based maximum power point tracking methods for photovoltaic systems operating under fast changing environments", in: Solar Energy,2013, vol. 89, pp.42-53.

[8] Chiu, C.S., "T-S Fuzzy maximum power point tracking control of solar power generation systems", in: IEEE Trans. Energy Convers.,2010, vol. 25, pp. 1123–1132.

[9] Vengatesh, R.P., Rajan, S.E.," Investigation of High gain MIC power converter for multicrystal PV module employing fuzzy logic technique", in: Automatika, 2016, vol. 57, no. 3, pp. 627-637.

[10] Sahnoun, M.A., Ugalde, H.M.R., Carmona, J.-C., Gomand, J.," Maximum power point tracking using P&O control optimized by a neural network approach: a good compromise between accuracy and complexity", In: Energy Procedia, 2013, vol. 42, pp. 650-659.

[11] Gavhane, P.S., Krishnamurthy, S., Dixit, R., Ram, J.P., Rajasekar, N.," EL-PSO based MPPT for Solar PV under Partial Shaded Condition", in: Energy Procedia, 2017, vol.117, pp. 1047–1053.

[12] Sera, D., Mathe, L., Kerekes, T., Spataru, S.V., Teodorescu, R.," On the perturb-and observe and incremental conductance MPPT methods for PV systems", in: IEEE J. Photovolt., 2013, vol. 3, no. 3, pp. 1070-1078.

[13] Ahmed, J., Salam, Z.," An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency", in: Applied Energy,2015, vol. 150, pp. 97-108.

[14] Li, S., Liao, H., Yuan, H., Ai, Q., Chen, K., "A MPPT strategy with variable weather parameters through analysing the effect of the DC/DC converter to the MPP of PV system", Solar Energy, 2017, vol. 144, pp. 175-184.

[15] Mei, Q., Shan, M., Liu, L., Guerrero, J.M., "A novel improved variable step-size incremental-resistance MPPT method for PV systems", in: IEEE Trans. Industr. Electron., 2011, Vol. 58, no. 6, pp. 2427-2434.

[16] Liu, F., Duan, S.,Liu, F., Liu, B., Kang, Y., " A variable step size INC MPPT method for PV systems", in: IEEE Trans. Industr. Electron., 2008, vol. 55, no. 7, pp. 2622-2628.

[17] Safari, A., Mekhilef, S.," Simulation and hardware implementation of incremental conductance MPPT with direct control method using Cuk converter", in: IEEE Trans. Industr. Electron., 2008, vol. 58, no. 4, pp. 1154-1161.

[18] Yan, Z., Fei, L., Jinjun, Y., Shanxu, D., "Study on realizing MPPT by improved Incremental Conductance method with variable step-size", in: 3rd IEEE Conference on Industrial Electronics and Applications, 2008, pp. 547–550.
[19] Chen, B.C., Lin, C.L., "Implementation of maximum-powerpoint- tracker for photovoltaic arrays", in: 6th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2011, pp. 1621–1626.
[20] Soon, T.K., Mekhilef, S., "A fast-converging MPPT technique for photovoltaic system under fast-varying solar irradiation and load resistance", in: IEEE Trans. Ind. Inform., 2015, vol., no. 11, pp. 176–186.
[21] Belkaid, A., Colak, I., Isik, O., "Photovoltaic maximum power point tracking under fast varying", in: Applied Energy, 2016, vol. 179, pp. 523-530.
[22] Motahhir, S., El Ghzizal, A., Sebti, S., Derouich, A., "Shading effect to energy withdrawn from the photovoltaic panel and implementation of DMPPT using C language", in: International Review of Automatic Control, 2018, vol. 9, no. 2, pp. 88–94.
[23] Isaloo, B.A., Amiri, P., "Improved step size Incremental Conductance MPPT method with high convergence speed for PV systems", in: Journal of Engineering Science and Technology, 2016, Vol. 11, no. 4, pp. 516–528.
[24] Radjai, T, Rahmani, L, Mekhilef, S, Gaubert, J.P., " Implementation of a modified incremental conductance MPPT algorithm with direct control based on a fuzzy duty cycle change estimator using dSPACE", in: Solar Energy, 2014, vol. 110, pp. 325–337.
[25] Bennett, T., Zilouchian, A., Messenger, R.,"Photovoltaic model andconverter topology considerations for MPPT purposes", in: Solar Energy, 2012, vol. 86, pp. 2029–2040.
[26] Ishaque, K., Salam, Z., Syafaruddin, "A comprehensive MATLAB Simulink PV system simulator with partial shading capability based on two-diode model", in: Solar Energy, 2011, vol. 85, pp. 2217–2227.
[27] Ishaque, K., Salam, Z., Taheri, H., "Simple, fast and accurate twodiode model for photovoltaic modules", in: Sol. Energy Mater. Sol. Cells, 2011, vol. 95, pp. 586–594.
[28] Gonzalez-Longatt, F.M., "Model of Photovoltaic Module in Matlab", in: Int. J. Comput. Technol. Elect. Eng. (IJCTEE),Cibelec, 2005, pp. 1-5.
[29] Adel,Y, Abdelhady, R., M. Ibrahim, A.,"Assessment of a proposed hybrid photovoltaic array maximumpower point tracking method", in: Water Science, 2016 , vol 30, pp. 108–119.
[30] Wang, Y.J., Hsu, P.C., "Modelling of solar cells and modules using piecewise linear parallel branches", in: IET Renew. Power Gener., **2011**, vol. 5, pp. 215–222.
[31] Al Tarabsheh, A., Akmal, M., Ghazal, M., "Series Connected Photovoltaic Cells—Modelling and Analysis", In: Sustainability, 2017, vol. 9, no. 3, pp. 1-9.
[32] Liu, X., Wang, Y.," Reconfiguration Method to Extract more Power from Partially Shaded Photovoltaic Arrays with Series-Parallel Topology", in: Energies, 2019, vol. 12, iss. 8, p. 1439.
[33] Chander, S., Purohit, A., Sharma, A., Arvind, Nehra, S.P., Dhaka, M.S., "A study on photovoltaic parameters of mono-crystalline silicon solar cell with cell temperature", in: Energy Rep., 2015, vol. 1, pp. 104–109.
[34] Sharma, V., Chancel, S.S., "Performance and degradation analysis for long term reliability of solar photovoltaic systems: A review.", in: Renew. Sustain. Energy Rev., 2013, vol. 27, pp. 753–767.
[35] Wuerfel, U., Neher, D., Spies, A., Albrecht, S.," Impact of charge transport on current–voltage characteristics and power-conversion efficiency of organic solar cells", in: Nat. Commun., **2015**, vol. 6, no. 6951.
[36] Aouchiche, N., Becherif, M., HadjArab, A., Aitcheikh, M.S., Ramadan, H.S., Cheknane, A." Dynamic Performance Comparison for MPPT-PV Systems using Hybrid Pspice/Matlab Simulation", in: Int. J. Emerg. Electr. Power Syst, 2016, vol. 17, no. 5, pp. 529–539.
[37] Dwivedi, L.K., singh, V., Pareek, A., Yadav, P., "MATLAB/ SIMULINK based study of series- parallel connected photovoltaic system under partial shaded condition", in: International Research Journal of Engineering and Technology (IRJET), 2016, vol. 03, Issue 10, pp. 809-815.
[38] Moller, HJ., "Semiconductors for solar cells", Norwood, Artech House, 1993.
[39] Schmidt, H., Schmid, J.,"Power conditioning for photovoltaic power systems", in: Handbook of Photovoltaic Science and Engineering, 2003, pp. 954-983.
[40] Akihiro, O., "Design and simulation of photovoltaic water pumping system", Doctoral thesis, Faculty of California, 2005.
[41] Park, S., Jahns T.M., "A Self-boost charge pump topology for a gate drive high-side power supply", in: IEEE Trans Power Electron, 2005, vol. 20, no. 2, pp. 300–307.

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