Article

On Improved PSO and Neural Network P&O Methods for PV System under Shading and Various Atmospheric Conditions

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Abstract: This article analyzes and compares the integration of two different maximum power point tracking (MPPT) control methods, which are tested under partial shading and fast ramp conditions. These MPPT methods are designed by Improved Particle Swarm Optimization (IPSO) and a combination technique between Neural Network and Perturb & Observe method (NN_P&O). These two methods are implemented and simulated for photovoltaic systems (PV), where various system responses, such as: voltage and power are obtained. The MPPT techniques were simulated using Matlab/Simulink environment. A comparison of the performance of IPSO and NN_P&O algorithms is carried out to confirm the best accomplishment of the two methods in terms of speed, accuracy and simplicity.

Keywords: Maximum Power Point Tracking (MPPT); Improved Particle Swarm Optimization (IPSO); photovoltaic (PV); Neural Network and Perturb & Observe method (NN-P&O)

1. Introduction

Regarding the profitable economic benefits of a clean environment and sustainable solar energy, the power generation across photovoltaic (PV) systems has recently been attracted great importance. However, the main disadvantage of PV systems is the low efficiency of converting sunlight into electricity [1]. In addition, the power generated by the PV module depends on environmental factors, namely solar radiation and atmospheric temperature. These factors affect the current-voltage (I-V) and power-voltage (P-V) characteristics of the photovoltaic system. Under uniform irradiation, the P-V curve of the PV array has a maximum power point (MPP) [2]. However, in the case of uneven irradiance, such as partial shading of certain photovoltaic modules or even certain photovoltaic cells, the PV characteristics become more complicated, showing multiple peaks, of which only one peak is the global peak (GMPP); whereas the others are local peaks (LMPP) [3].

Therefore, a control technique called "Maximum Power Point Tracking" (MPPT) must be applied to make the best use of the available power under all operating conditions [4]. So far, many MPPT controllers have been proposed and implemented in the literature [5,6]. These controllers have some common requirements, such as low complexity, low cost, minimum output power fluctuation, and the ability to quickly track when the working conditions change [7]. The most widely used algorithms are Perturbation and Observation (P&O) and Incremental Conductance (InC) [8]. These conventional methods achieve moderate performance with easy implementation and low cost. In order to obtain better transient and steady-state performance, artificial intelligence-based MPPT technologies have been proposed, such as fuzzy logic and artificial neural network controllers (ANN) [9]. Furthermore, it turned out that the ANN controller has good performance under rapidly changing irradiance and partial shading, especially in terms of efficiency and response time [10]. The combination of two methods: ANN and fuzzy logic, that is can be found in [11, 12], is used to track MPP of PV systems. After collecting an experimental data, ANN is trained offline to define a reference voltage, that is the absciss of the MPP. Then, the reference voltage and the instantaneous voltage are compared to precise the signal error. The signal and the change of the error are used as the FLC inputs. The FLC generates a duty cycle value for the pulse width modulation (PWM). This last is applied for the purpose of switching the boost converter which connects the PV panels to the load. The main drawback of this method is that it needs a lot of data for training.

Improved Particle Swarm Optimization (IPSO) method, was introduced in [13], has the capacity to locate the MPP, where the positions of the PSO particles correspond to duty cycles. IPSO has a high potential for MPPT due to the fast computation capability regardless of partial shading.

The emphasis of this paper will be on theoretical comparisons between two techniques, namely the improved PSO and NN_P&O, taking partial shading conditions into account. As a result, the aim of this research is to compare two MPPT algorithms in order to determine which technique performs better. The efficiency of the algorithms is assessed using a power calculation that values total energy generated by the panel during a time interval. In the simulations, the MPPT techniques under consideration were implemented exactly as described in the references. It should be noted that, a standalone photovoltaic system, that is built by connecting the Boost converter between the photovoltaic panel and a dc load, is considered for the study.

The paper is organized as follows: Section 2 introduces the PV model and presents its features, while Section 3 describes the two MPPT techniques. The comparison and discussion are illustrated in Section 4. Finally, in Section 5, the conclusion is presented.

2. Photovoltaic modeling and features

2.1. PV panel model

Solar cells can be illustrated using a variety of models. The single diode shown in Fig.1 is one of the most well-known circuits [14-17].

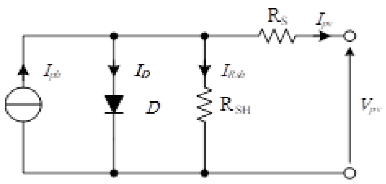

Figure 1. PV cell model.

The following equation (1) describes the relationship between the module's output current Ipv and its voltage Vpv:

$$I_{pv} = I_{ph} - I_0 \times \left(e^{\left(\frac{V_{pv} + I_{pv} \times Rs}{V_t}\right)} - 1 \right) - \frac{V_{pv} + I_{pv} \times Rs}{R_{sh}} \quad (1)$$

Vt is the thermal voltage:

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

Where Iph is the light generated current, which depends on the irradiance, G, and the cell temperature Tc , Rs is the series resistance, RSH is the shunt resistance, q is the charge of the electron, k is the Boltzmann's constant, T is the PN junction temperature and ns is the number of series cells in module.

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2.2. PV characteristics

The PV module considered in this work is the polycrystalline BP Solar MSX 120, whose parameters are evaluated in Table 1.

Table 1. Parameters of BP MSX-120 panel.

Maximum power	Pmp	120 W
Voltage at Pmp	Vmp	33.7 V
Current at Pmp	Imp	3.56 A
Series resistance	Rs	0.4728Ω
Shunt resistance	Rsh,ref	1365.8Ω
Short circuit current	IscSTC	3.87 A
Open circuit voltage	VocSTC	42.1 V

This PV module comprises of 72 polycrystalline silicon sunlight based cells electrically orchestrated as four arrangement strings of 18 cells. In this work, the 72-cell arrangement setup with 4 bypass diodes is considered [18].

2.3. Influence of uniform irradiance

Under an ordinary condition, when the PV panel get different values of uniform irradiance, the P-V curves show one MPP for each curve, as presented in Figure 2.

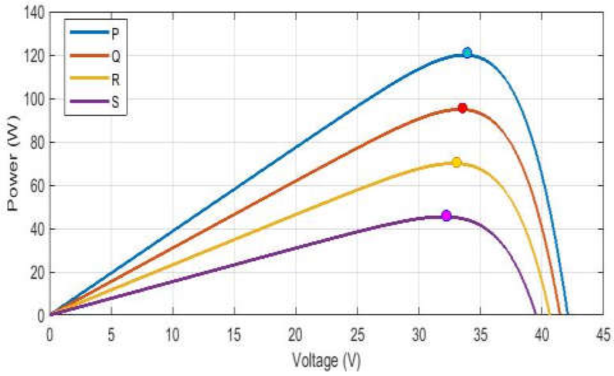

Figure 2. P-V curves in different uniform irradiance conditions.

The MPPs which composed of maximum power (Pmpp) and the optimal voltage (Vmpp) were determined in Table 2.

Table 2. Pmpps and Vmpps values extracted under different uniform irradiance and Tc=25°C.

Set	Irradiance (W/m^2)	Vmpp	Pmpp
P	1000	33.70	119.9720
Q	600	32.79	69.9888
R	800	33.33	94.90
S	400	31.94	45.3924

2.4. Influence of partial shading condition

When the partial shading happens, the shaded string of the panel will not create as much current as the unshaded strings. This downside is defeated by utilizing a bypass diode that permits the current of the unshaded cells to bypass the shaded cell. The changes in irradiance of shading panel area (GS) and non-shading panel area (G) were realized in four sets, as shown in Figure 3 and Table 3. Figure 3 shows that each P–V curve was characterized by two peaks designed by Global MPP (GMPP) and local MPP (LMPP) [19].

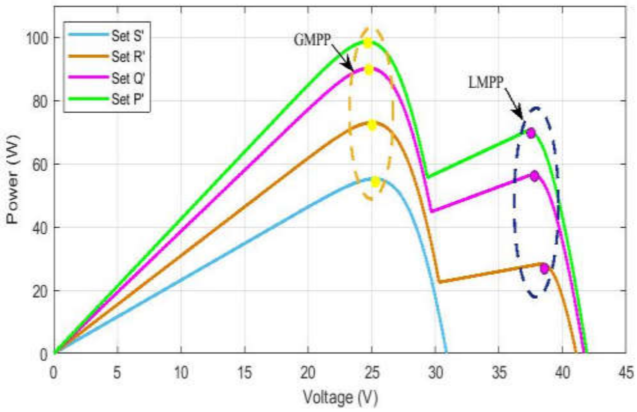

Figure 3. P-V curves in different partial shading conditions.

Table 3. MPPs values extracted under different uniform irradiance.

Set	G	GS	GMPP		LMPP	
			Vmpp	Pmpp	VLMPP	PLMPP
P′	1000	600	25.18	90.2943	37.75	56.89
Q′	600	600	25.18	55.2495	25.18	55.24
R′	800	600	25	73.076	38.48	28.50
S′	1100	600	24.63	98.6604	37.36	70.69

3. MPPT control techniques

The output power characteristics of PV systems vary with irradiance, temperature and partial shading conditions in non-linear manner [20]. In this case, the MPP of the PV array will change continuously. Therefore, the operating point of the photovoltaic system must be changed to the maximum energy produced [21]. Therefore, the MPPT technology is used to maintain the operating point of the PV array at its MPP [22]. There are many MPPT techniques available in the literature; the considered methods in this work are described in the following sections.

3.1. IPSO Method

The Improved PSO (IPSO) algorithm, called cooperative particles, consists of solving the problem of nonlinear systems optimization using a group of Np particles $(P_i)_{2\leq i\leq Np}$. This technique is based on six steps [23–26]:

- Step 1: Initialize *Np*, *w*, α and β parameters which are integrated in equation (3).

$$\Delta D_i^{k+1} = w \times \Delta D_i^k + \alpha\left(D_{Pbesti} - D_i^k\right) + \beta\left(D_{Gbest} - D_i^k\right) \quad (3)$$

Where the weighted summation of three criteria ω, α and β is equal to 1; ΔD_i^{k+1} is the perturbation in the present position; ΔD_i^k is the perturbation in the previous position; DGbest is the global best position of the leader swarm particle; D_{Pbesti} is the local best position of each particle of index *i*.

- Step 2: Initialize the *k*-th iteration and the index of the *i*-th particle at 1.

- Step 3: If $k \leq N_p$, the command which will be generated by *i*-th particle is determined by applying equation (4).

$$D_i = \gamma, 1 \leq i \leq Np \quad (4)$$

Where γ is a random number in $\left[D_{\inf}..D_{\sup}\right]$

If $k>N_p$ the algorithm selects the i-th particle, which satisfies the following condition : the division remainder of (k-i) by N_p is equal to 0, in order to complete the step and the new duty cycle D_i using the following equation.

$$D_i^{k+1} = D_i^k + \Delta D_i^{k+1} \quad (5)$$

Where D_i^{k+1} is the new position and D_i^k is the actual position;

- Step 4: Send the command U= D_i to the Boost converter. Measure the voltage V_{pv} and current I_{pv} to calculate the output power that corresponds to the i-th particle.

- Step 5: The i-th particle must update its own best duty cycle which is designated D_{PBesti}. Moreover, it is necessary to put a comparison between the best powers generated by N_p particles during k iteration in order to update D_{Gbest} generated by the leader particle.

- Step 6: If the convergence of each duty cycle produced by the particle i to D_{Gbest} is not reached yet, k is increased by 1 and return to step 3. If D_{Gbest} is reached by all the particles that is to say $(D_{Pbesti})_{1\leq i\leq Np} = D_{Gbest}$ then the converter must be operating in a regular way with this optimal duty cycle until a change in the environmental conditions occurs which causes the return to step 2 for tracking the new MPP.

These steps were summarized in the following flowchart:

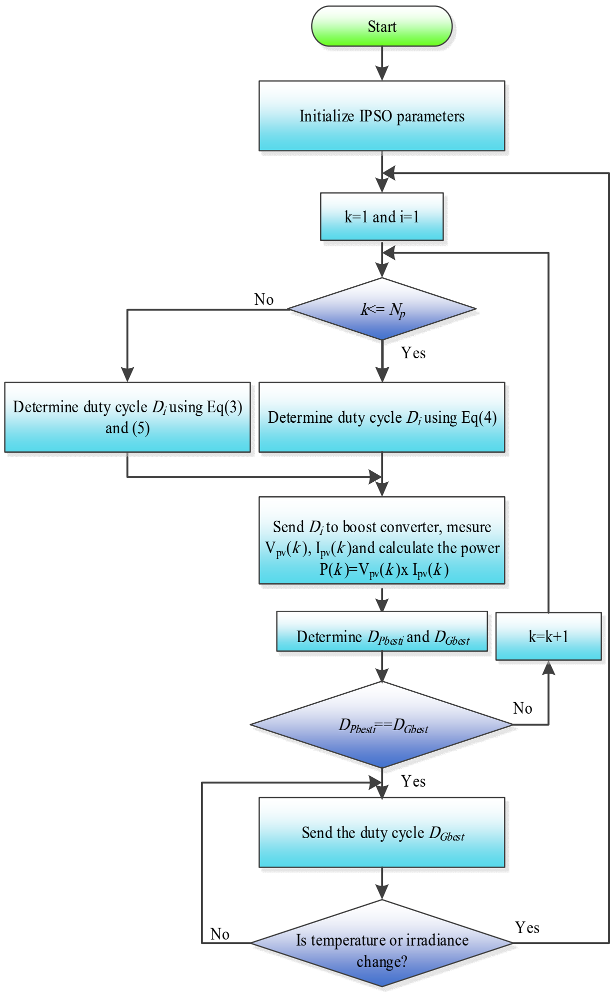

Figure 4. Flowchart of the IPSO-based MPPT algorithm

 doi:10.20944/preprints202207.0386.v1

3.2. NN_P&O Method under partial shading conditions

In order to keep the power level at the peak state and improve the energy efficiency, no matter how the environment changes, the NN_P&O technique based on the two controllers, Neural Network (NN) and Perturb & Observ (P&O) methods, has been simulated [24]. The selected structure of the NN_P&O includes three simple layers: input, hidden and output layers. The input layer has 2 nodes, the hidden layer has 8 nodes, and the output layer has 1 node, as illustrated in Figure 5.

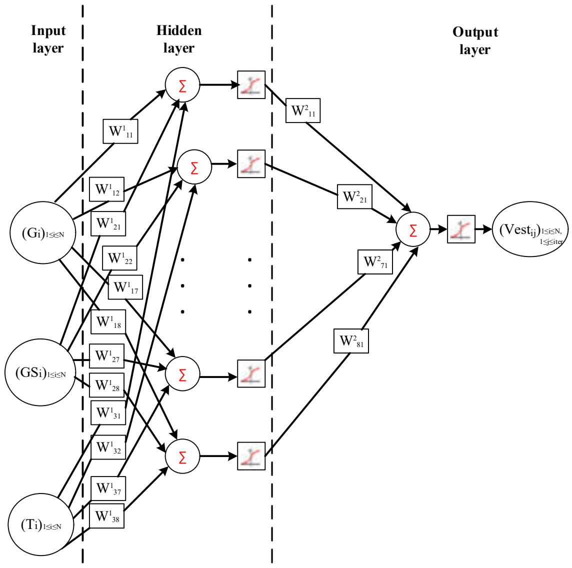

Figure 5. Configuration of the utilized NN under partial shading.

The main idea of the NN_P&O algorithm is using the NN controller to predict the voltage value $(Vest)$ during the variation of irradiation in shading and non shading area, respectively, ΔG and ΔGS are different than zero. Otherwise, the P&O method involves a very small step size to reach the MPP. This algorithm can be presented in the following flowchart (Figure 6):

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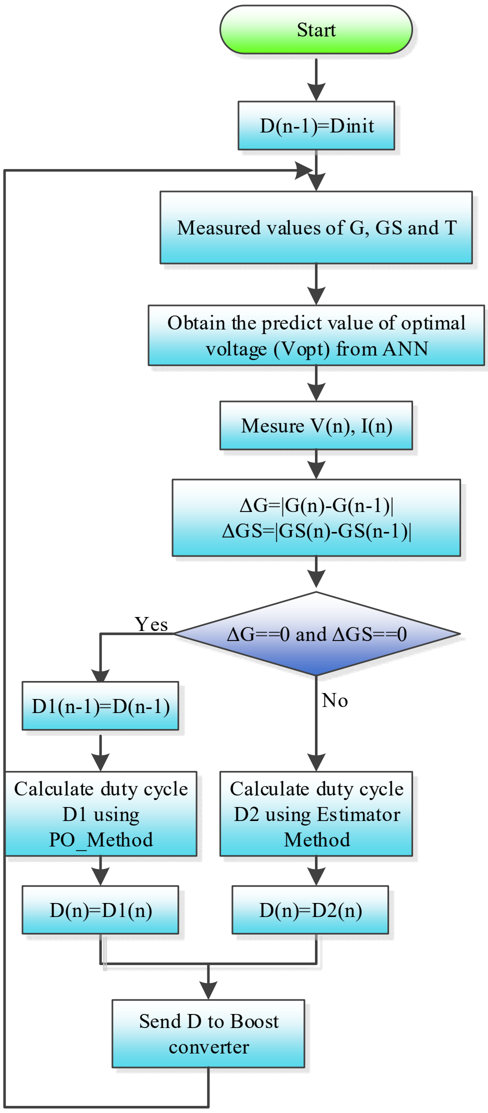

Figure 6. Flowchart of the NN_P&O method.

4. Simulation results under various atmospheric conditions

In order to reveal the characteristics of the NN-P&O and the IPSO methods, different environmental conditions were adopted and applied on the PV system.

4.1. Results and discussion under shading

To check the accomplishment of the NN-P&O and IPSO techniques, the two algorithms were incorporated in Matlab/Simulink environment under shading, as exhibited in Figure 3 and Table 3. The simulation results are presented in Figure 7.

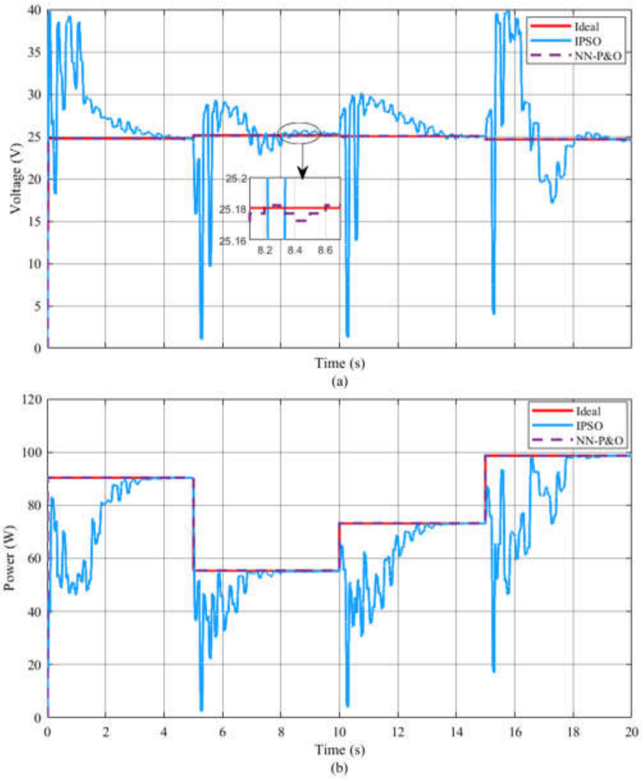

Figure 7. Simulation results under shading given by NN-P&O and IPSO algorithms: (a) Voltage under shading, and (b) Power under shading.

Figure 7 shows not only the ability of the NN-P&O and the IPSO algorithms to follow the GMPP but also the decrease in transient response (Tr) when the NN-P&O was applied. Indeed, it approves that the IPSO method is able to follow GMPP without oscillations around ideal point. To compare the efficiency and the effectiveness of the two techniques, the average accuracy in the steady state (Ass) was calculated relying on equation (6):

$$A_{ss} = \left(\frac{P_{ss}}{P_{mpp}} \right) \times 100 \quad (6)$$

where Pss indicates the power in steady state.

Table 4. Performances comparison between NN-P&O and IPSO under shading.

Algorithm	Set	Pss (W)	Ass (%)	Tr(s)
NN-P&O	P′	90.2943	99.99	0.2003
D=0.001	Q′	55.2495	99.99	0.0003
	R′	73.076	99.99	0.7003
	S′	98.6604	99.99	0.0003
IPSO	P′	90.2913	99.99	3.96
	Q′	55.2495	100	3.26
	R′	73.0760	99.99	3.26
	S′	98.6604	99.99	3.66

Table 4 confirms that the response time when applying NN-P&O is shorter than when applying IPSO. Moreover [27] shows that when the duty cycle is small the response time becomes larger so the precision increases and the value of Ass is almost the same as IPSO. An observation that can highlight the IPSO is that if the irradiation level remains constant for a long time, Ass can reach 100%. While when using the NN-P&O, the pv system can never reach this value.

4.2. Results and discussion under various irradiation slopes

The different algorithms P&O, NN and NN-P&O are incorporated in Matlab/Simulink under ramp irradiation, as seen in Figure 8 and 9.

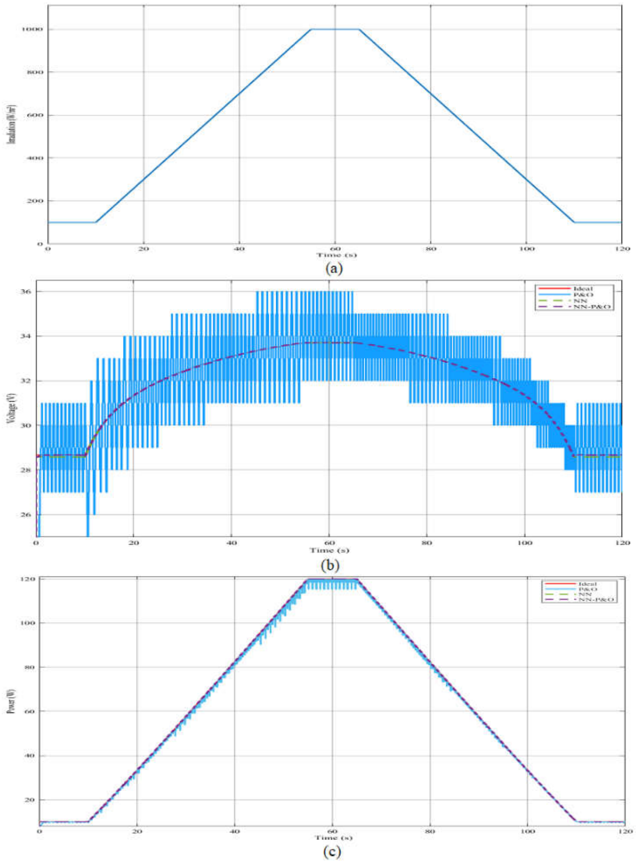

Figure 8. Simulation results under a slope of 20 W/m2 /s: (a) Irradiance, (b) Voltage, and (c) Power.

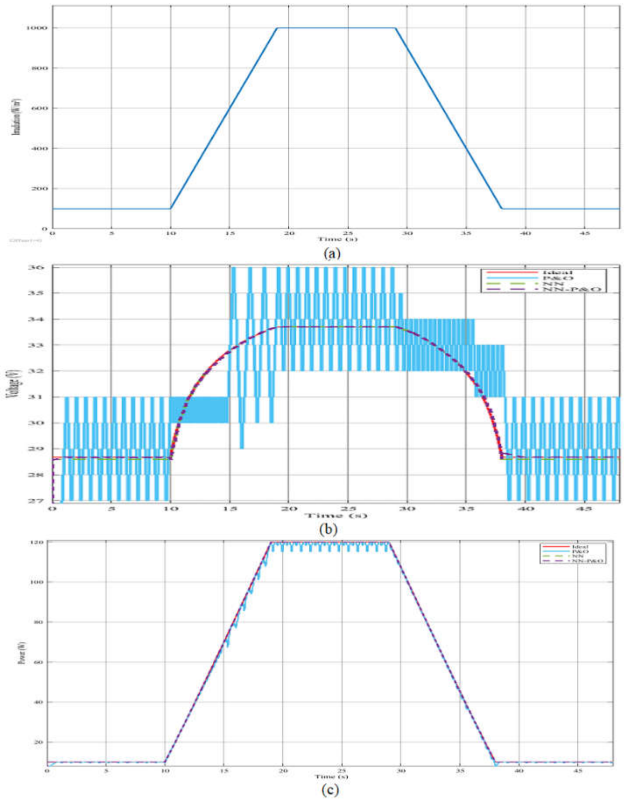

Figure 9. Simulation results under a slope of 100 W/m2 /s: (a) Irradiance, (b) Voltage, and (c) Power.

Figure 8a and 9a presented two trapezoidals irradiation profiles: The first starts at 10s with a positive slope from 100W/m2 to 1000W/m2 in 45 seconds, followed by a 10 seconds steady state period, and finally returns to 100W/m² irradiation in 45 seconds. The second trapezoidal starts at 10s from 100W/m², reaches its maximum (1000 W/m²) at 9 s, keeps the steady state for 10s and arrives back to its initial value at 38s. This profile is used to compare NN-P&O technique with P&O and NN.

Figures 8b and 9b show that the P&O method cannot track correctly the MPP exactly under fast ramp irradiance, where the PV voltage is largely oscillating around the MPP one. This has caused the harvested power to be less than the maximum available one. However, the MPP was tracked properly when the NN method was applied but with small error around the MPP voltage, causing smaller power loss, as shown in Figure 8c and 9c. To enhance the precision at steady state, a combination of the two methods: P&O with a small duty cycle, which is used when the irradiation is constant and an NN technique, which is integrated under fast ramp irradiation. The results of this hybrid method show that the obtained V-P are almost similar to MPP values. In order to determine the precision of P&O, NN and NN-P&O techniques, the efficiencies were mesured under the trapezoidals irradiation exhibited previously, showing the efficiencies presented in Figure 10 and 11 below.

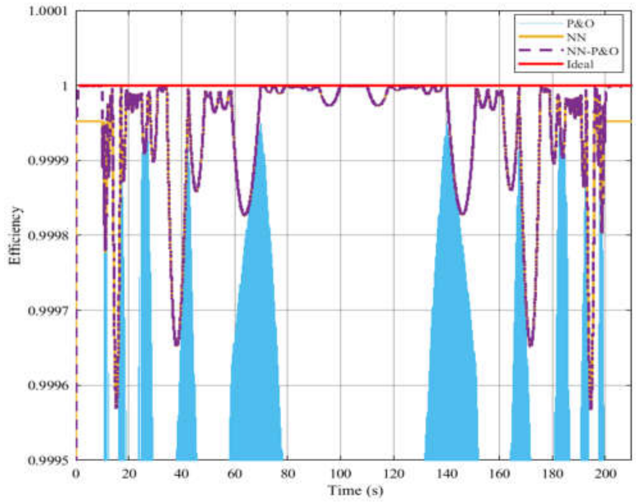

Figure 10. Efficiency of three MPPT methods under a slope of 20 W/m2 /s.

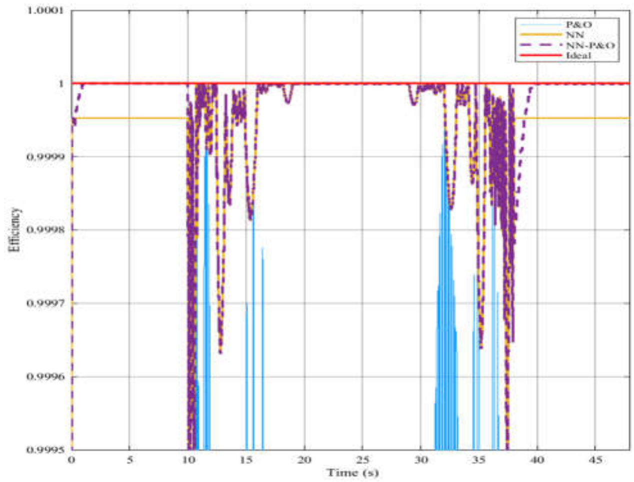

Figure 11. Efficiency of three MPPT methods under a slope of 100 W/m2 /s.

Figure 10 and 11 confirm that the integration of NN oder NN-P&O to control PV system enhance clearly the efficiency compared with the classical P&O algorithm. Moreover, if the slope value increases the P&O efficiency decreases. Hence the inaccuracy of P&O algorithm. These figures indicate that the NN-P&O error at steady state is negligible relative to NN error.

To prove this interpretation, the average efficiency of every technique: P&O, modified InCond, NN, dP-P&O, LI-PSO and NN-P&O is evaluated by equation 7.

$$E_f = \frac{\sum_{i=1}^{n} \left(\frac{P_{mpp} - P_{ss}}{P_{mpp}} \right)_i}{n} \times 100 \quad (7)$$

Table 5 below shows that NN-P&O efficiency is superior to the other techniques. It is equivalent to 99.995% under a slope of 20 W/m2/s and equal to 99.997% under a slope of 100 W/m2/s. This proves the better performance of NN-P&O method in MPP tracking.

Table 5. Efficiencies Values.

Algorithm	Slope (W/m²s)	Ef (%)
P&O	20	96.443
Modified IncCond		99.5034
NN		99.994
dP-P&O		-
LI-PSO		99.94
NN-P&O		99.995
P&O	100	94.276
Modified IncCond		99.4622
NN		99.996
dP-P&O		97.05
LI-PSO		99.97
NN-P&O		99.997

7. Conclusions

The aim of this work is to highlight the NN-P&O performances through the comparison between this method with IPSO technique under shading and with other methods under fast ramp. The NN-P&O is the association of two interesting methods: P&O and NN which are incorporated to command the PV system output power through a dc- dc converter. This hybrid method has big effects on response time duration that is devoted to reach the operating point as well as on stability around the MPP. The obtained results confirm that NN-P&O is able to track the MPP very quickly whatever the environmental conditions are. But this tracking is accompanied by error which occurred in the training step of neural networks. This error becomes negligible when P&O method is integrated with a very small duty cycle. This leads to which implies very small oscillations around the MPP. Whereas the IPSO method is characterized by stability and a very long response time. In future work a developed PSO is required to track MPP in fast ramp environmental conditions.

Author Contributions: Conceptualization, W.H., D.S. and E.O.; methodology, W.H., D.S. and E.O.; software, W.H., D.S., E.O and A.L.; validation, W.H., D.S., E.O and A.L.; formal analysis, D.S., E.O and A.L.; investigation, W.H.; data curation, D.S., E.O and A.L.; original draft preparation, review and editing, W.H., D.S., E.O and A.L.; supervision, D.S., E.O and A.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors would like to thank Sergiu Spataru— Department of Photonics Engineering - Aalborg University, Denmark—for his support.

Conflicts of Interest: The authors declare no conflict of interest

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