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MODELING AND TESTING OF MAXIMUM POWER POINT TRACKING ALGORITHMS FOR PHOTOVOLTAIC SYSTEMS

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In this paper a MATLAB simulation model of a photovoltaic system was developed in order to analyze how the Perturbe&Observe, Incremental Conductance and Fuzzy Logic Control algorithms track the MPP under various shading scenarios, set the standard in effect on "overall efficiency of photovoltaic inverters connected to network". The MATLAB model proves to be a useful tool that allows real-time observation of how the response of a MPPT algorithm facilitating subsequent optimization of these algorithms.

Keywords: Maximum Power Point Tracking, Perturbe and Observe, Incremental Conductance, Fuzzy Logic Control

1. Introduction

Nowadays, one of the most important subjects of the photovoltaic optimization field is to improve tracking of the maximum power point (MPPT). This matter can be achieved by creating, adapting and implementing new control algorithms to be later used in photovoltaic plants, respectively in the PV inverters. The optimizations should increase power generation and consequently reduce the operating cost of PV plants. In order to decide which algorithm is more suitable for an photovoltaic application and which one tracks best the MPP, there was the need of a standard to regulate the way the inverters should response for different case scenarios.

In 2011, Romanian Standards Association approved a new standard for performance characterization of PV inverters [1], which specifies how to statically and dynamically test the efficiency of MPPT methods. Until now, there are no papers to compare the results of these three algorithms under the conditions scenarios described in the standard EN50530.

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The objective of this article is to analyze and test according to the standard the most three well known MPPT algorithms, Perturbe&Observe (P&O), Incremental Conductance (IncCond) and Fuzzy Logic Control (FLC).

2. Simulation model

In this paper, a simulation model was created for testing the performance of different MPPT algorithms mentioned above, without taking into account the type of converter is used. In order to perform extensive simulations for the different case scenarios that the standard requires and have to overcome the computational limitation of the ordinary personal computers, the simulation model (Fig. 1) of the PV array was developed in Matlab/SIMULINK based on papers [2]-[9].

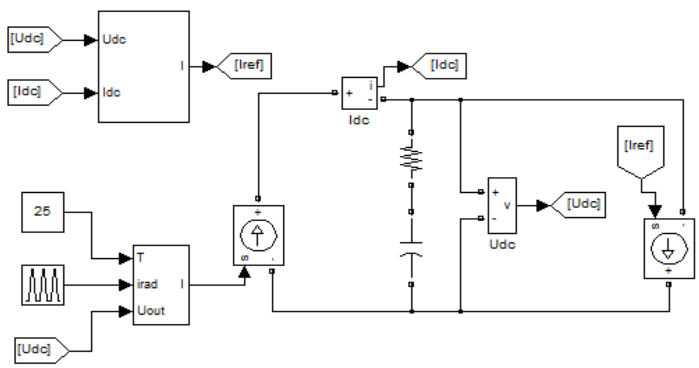

Fig. 1. Matlab/SIMULINK model.

The MPPT algorithm creates U_{ref} and is converted to I_{ref} using the control scheme described in [10] and shown in Fig. 2.

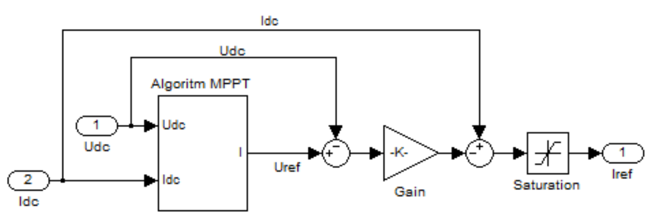

Fig. 2. MPPT Control block.

In order to respect the parameters of the inverter, U_{MPP} have to be at least equal or to be greater with the peak line-to-line voltage (563,38V) and the power have to be greater than 10kW. The photovoltaic panel parameters at standard test conditions are U_{OC}=845.46V, U_{MPP}=697.62V, I_{SC}=18.44A, I_{MPP}=17.66A.

Starting from the standard testing scenarios and the model presented earlier, the Perturbe&Observe, Incremental Conductance and Fuzzy Logic Control algorithms were dynamically tested. The standard implies slopes with different gradients from 0.5 to 100 $W/m^2/s$ and different irradiance levels, from low to medium irradiance, 100 to 500 W/m^2, and from medium to high, 300 to 1000 W/m^2, shown in Table 1 and Table 2 respectively [11] and [12].

Table 1

Slopes proposed for irradiance levels from 100 to 500 W/m^2

Slope ($W/m^2/s$)	Ramp time (s)	Dwell time (s)	Simulation time (s)
0.50	800.00	10.00	1630.00
1.00	400.00	10.00	830.00
2.00	200.00	10.00	430.00
3.00	133.00	10.00	296.00
5.00	80.00	10.00	190.00
7.00	57.00	10.00	144.00
10.00	40.00	10.00	110.00
14.00	29.00	10.00	88.00
20.00	20.00	10.00	70.00
30.00	13.00	10.00	56.00
50.00	8.00	10.00	46.00

Table 2

Slopes proposed for irradiance levels from 300 to 1000 W/m^2

Slope ($W/m^2/s$)	Ramp time (s)	Dwell time (s)	Simulation time (s)
10.00	70.00	10.00	170.00
14.00	50.00	10.00	130.00
20.00	35.00	10.00	100.00
30.00	23.00	10.00	76.00
50.00	14.00	10.00	58.00
100.00	7.00	10.00	44.00

Because the FLC algorithm doesn't manage to track MPP for slopes under 5 $W/m^2/s$ and in order to test the Perturbe&Observe, Incremental Conductance and Fuzzy Logic Control algorithms, there were chosen three different slopes from Table 2: 20, 50 and 100 $W/m^2/s$. Also, the sampling frequency of the MPPT algorithm is set to 25 Hz because the dynamics of the weather conditions is slow compared to the dynamics of systems typically studied in control theory according to [8]. The sampling frequency of the voltage and current measurements is set to 20 kHz.

3. Perturb&Observe

In the MPPT Algorithm block represented in Fig. 2 it was implemented the Perturbe&Observe algorithm, described in Fig. 3.

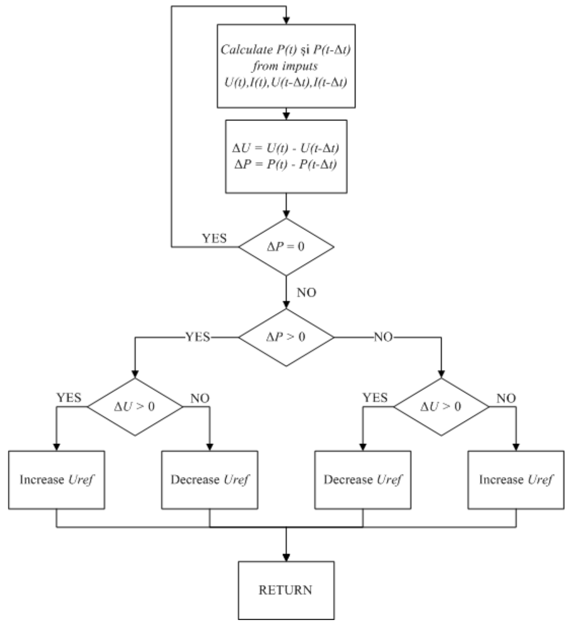

Fig. 3. Flowchart of Perturbe&Observe MPPT algorithm

The first slope has a gradient of 20 $W/m^2/s$, the second one of 50 $W/m^2/s$ and the last one of 100 $W/m^2/s$. Fig. 4 illustrates the results of the test.

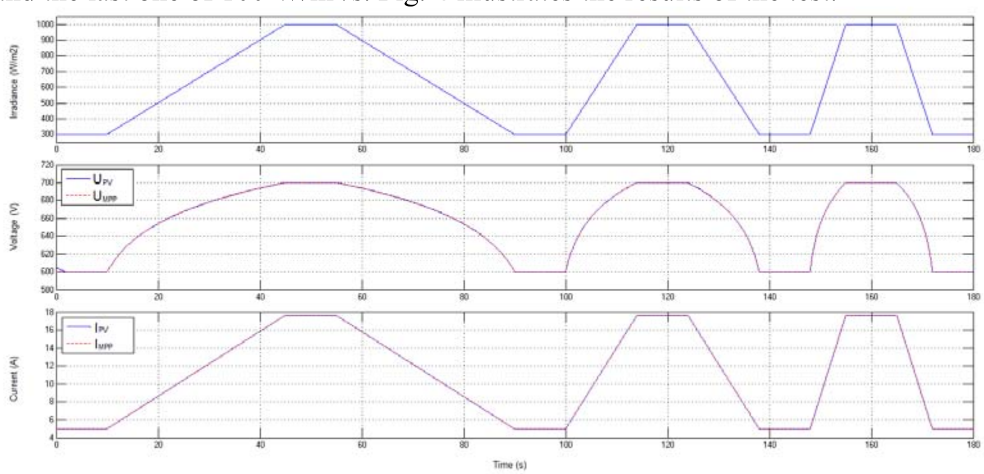

Fig. 4. MPP tracking with Perturbe&Observe algorithm under slopes of 20, 50 and 100 $W/m^2/s$

Because for slopes lower than 5 $W/m^2/s$, some algorithms doesn't manage to track MPP, it was simulated for each algorithm for slopes higher than 10 $W/m^2/s$.

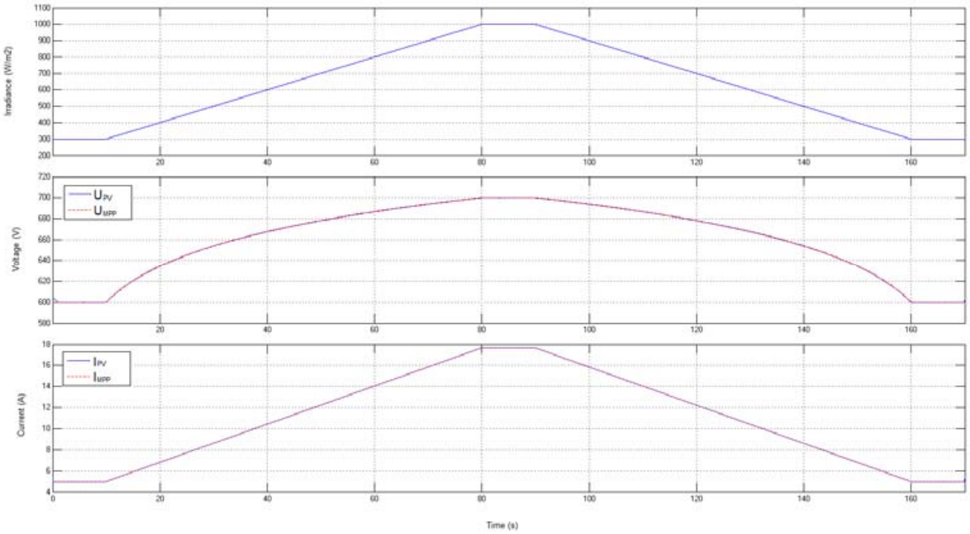

Fig. 5. MPP tracking with Perturbe&Observe under a slope of 10 W/m²/s

4. Incremental Conductance

In the MPPT Algorithm block represented in Fig. 2 it was implemented the Incremental Conductance algorithm, described in Fig. 6.

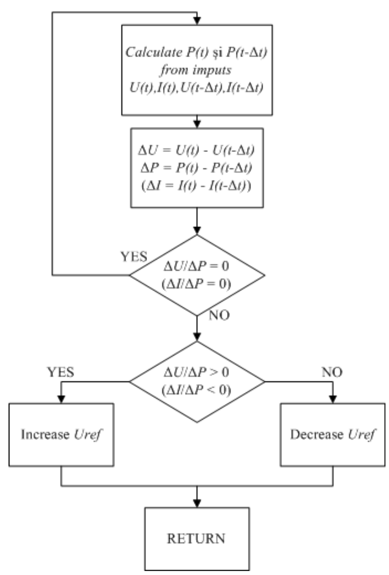

Fig. 6. Flowchart of Incremental Conductance MPPT algorithm

The same tests realized for Perturbe&Observe algorithm were reproduced for the Incremental Conductance algorithm, and are illustrated in Fig. 7 and Fig. 8. The results are very similar with the first algorithm.

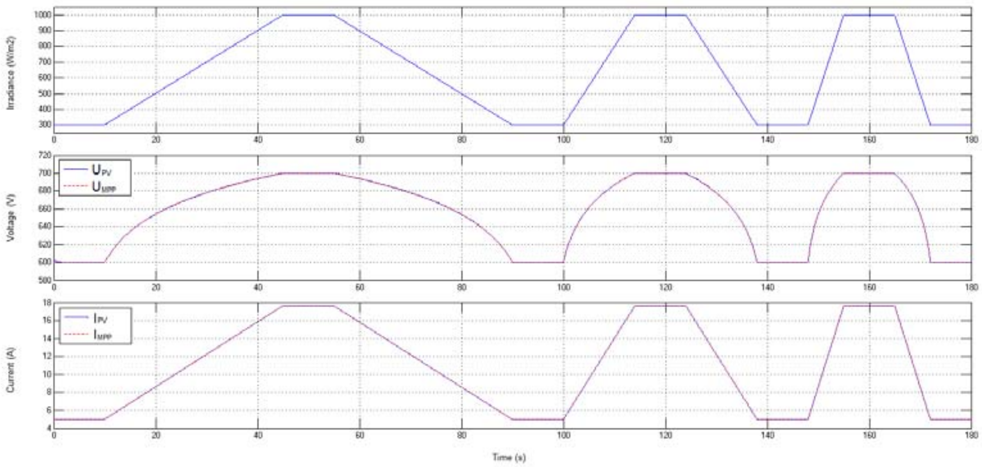

Fig. 7. MPP tracking with Incremental Conductance algorithm under slopes of 20, 50 and 100 $W/m^2/s$.

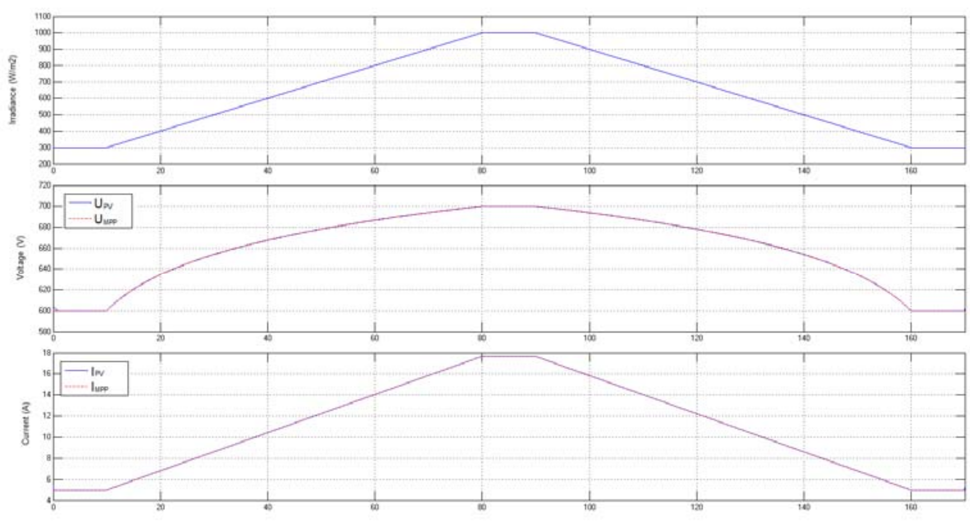

Fig. 8. MPP tracking with Incremental Conductance algorithm under a slope of 10 $W/m^2/s$.

5. Fuzzy Logic Controller

For testing FLC algorithm were used the parameters of the system used before with a slightly difference, the MPP Controller block was replaced with a Fuzzy Logic Controller block. Usually, the inputs of the inference system are represented as an error (1) and as a change in the error (2). The increment in the reference voltage represent the output and is transformed in reference current using the scheme depicted in Fig. 2. For each variable have been used seven triangular membership functions according to the rule base presented in Table 3.

Table 3

Fuzzy Logic Control Rule base

E\ΔE	**BN**	**MN**	**SN**	**ZE**	**SP**	**MP**	**BP**
BN	BN	BN	BN	BN	MN	SN	ZE
MN	BN	BN	BN	MN	SN	ZE	SP
SN	BN	BN	MN	SN	ZE	SP	MP
ZE	BN	MN	SN	ZE	SP	MP	BP
SP	MN	SN	ZE	SP	MP	BP	BP
MP	SN	ZE	SP	MP	BP	BP	BP
BP	ZE	SP	MP	BP	BP	BP	BP

Usually Fuzzy Logic Control have two inputs, an error, E, and the change in the error, ΔE:

$$E = \frac{P_k - P_{k-1}}{V_k - V_{k-1}} \tag{1}$$

$$\Delta \mathrm{E} = E_k - E_{k-1} \tag{2}$$

The membership functions for the input variable E, ΔE and ΔU_{ref} are represented in Fig. 9(a), 9(b) and 9(c).

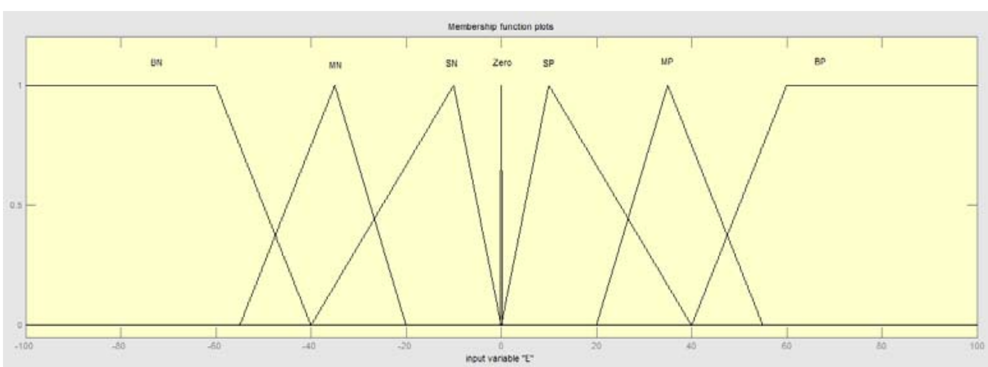

Fig. 9(a). Membership functions of the input variable E

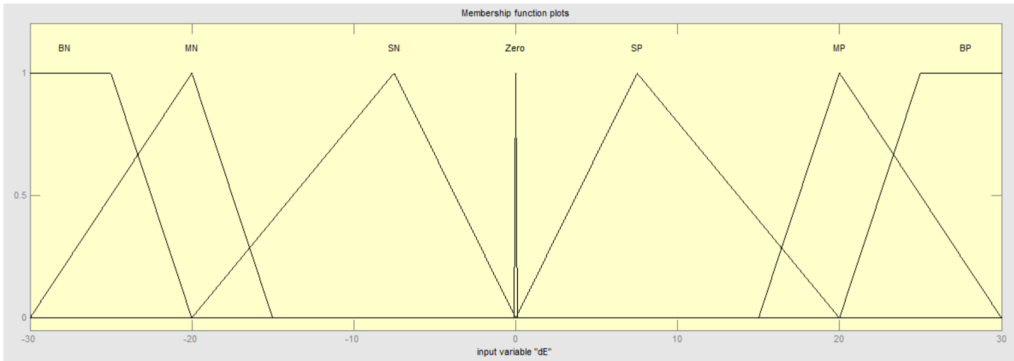

Fig. 9(b). Membership functions of the input variable ΔE

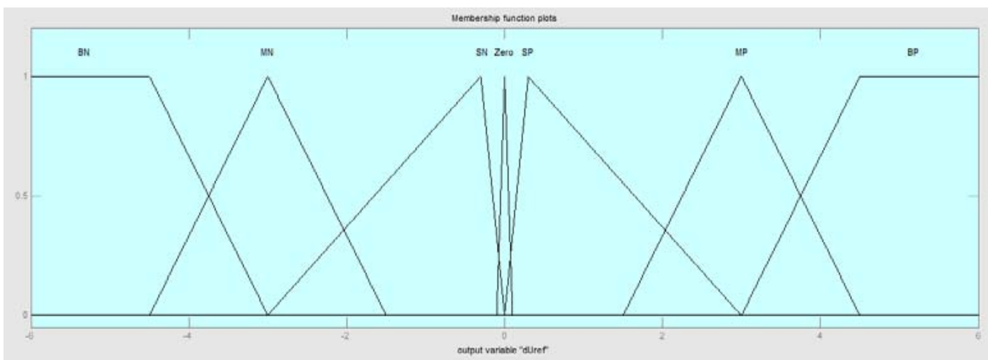

Fig. 9(c). Membership functions of the output variable ΔU_{ref}

The behavior of the Fuzzy Logic Control algorithm can be observed in Fig. 10 and Fig. 11.

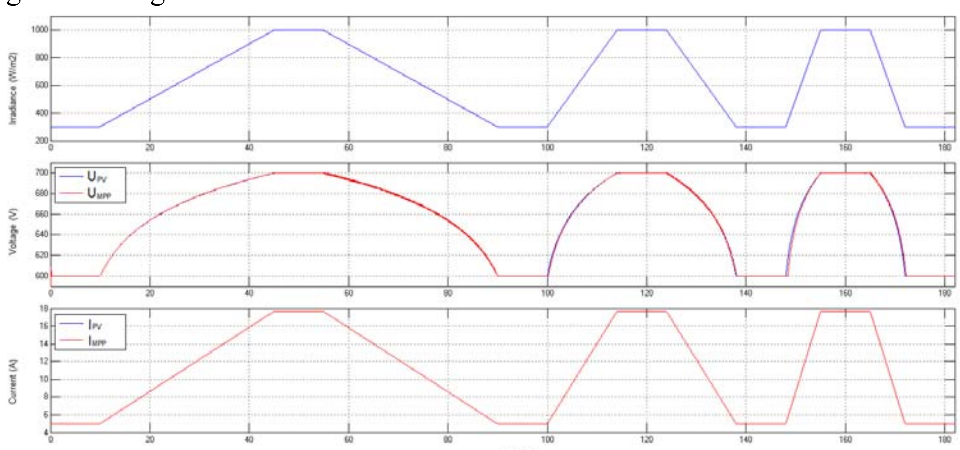

Fig. 10. MPP tracking with Fuzzy Logic Control algorithm under slopes of 20, 50 and 100 $W/m^2/s$

For slopes above 10 W/m^2/s the results of FLC algorithm are satisfactory.

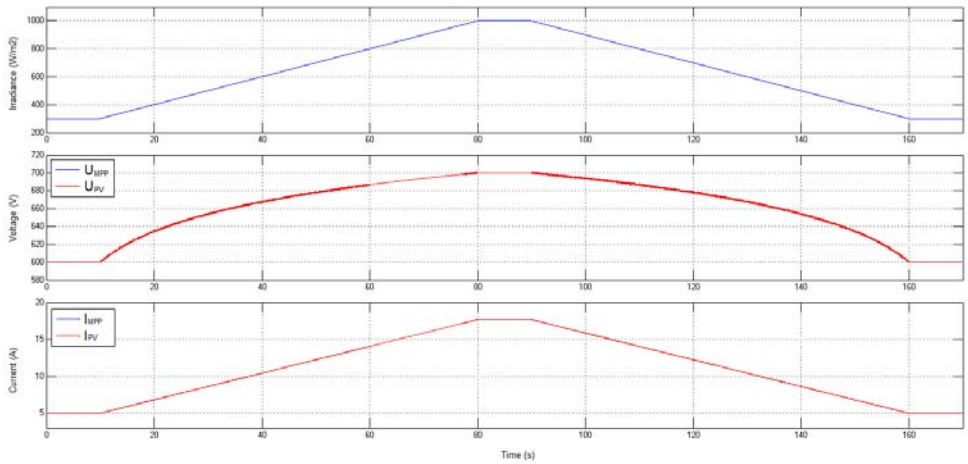

Fig. 11. MPP tracking with Fuzzy Logic Control algorithm under a slope of 10 W/m^2/s.

6. Conclusions

In this paper, three simple and effective MPPT algorithms (Perturbe&Observe, Incremental Conductance and Fuzzy Logic Control) were selected for simulations under different case scenarios described in performance characterization of PV inverters standard.

For testing purposes, a simplified PV system model was developed. Because was needed a long enough simulations so that the dynamic MPPT efficiency can be tested, the power converter was replaced with a controlled current source.

Table 4

MPPT Algorithms Efficiency

Slope [W/m^2/s]	Efficiency (%)		
	P&O	IncCond	FLC
10	99.5117	99.5102	99.5083
14	99.5090	99.5035	99.4981
20	99.5033	99.5030	99.4938
30	99.4953	99.4945	99.4794
50	99.4838	99.4839	99.4750
100	99.4624	99.4618	99.4317

The simulations of the Perturbe&Observe, Incremental Conductance and Fuzzy Logic Control algorithms were compared and based on the results of the dynamic efficiency tests (Table 4) and it was concluded that the Perturbe&Observe algorithm perform better than the other two algorithms, respectively Incremental Conductance and Fuzzy Logic Control.

Fuzzy logic cannot be discarded based on these results alone, but it wasn't performed well under conditions of changing irradiance, and especially for slopes lower than 5 $W/m^2/s$.

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