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Matlab/Stateflow Based Modeling of MPPT Algorithms

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***Abstract*—Maximum power point tracker (MPPT) is an important part of photovoltaic system for extracting maximum power from photovoltaic array. MPPT is basically a dc-dc converter. MPPTs are controlled by MPPT algorithms and a number of MPPT algorithms are proposed in literature. Some of the proposed MPPT algorithm is commonly used in applications. In this paper, four commonly used MPPT algorithms (Perturbation&Observe, Incremental Conductance, Only Current Photovoltaic and Short Circuit Current) are modelled with Matlab/Stateflow. These algorithms are tested with Matlab/Simulink model and results are presented.**

Keywords—matlab/stateflow model, mppt algorithm, pv system

I. Introduction

In recent years, photovoltaic (PV) system applications are rapidly increasing in parallel with renewable energy system applications. Demand for PV system is expected to be continued in the future. PV systems convert solar energy directly into the electric energy. However, the conversion efficiency (radiation/electric power) of PV system is very low and when they are connected directly to a loads, maximum power is not transferred [1]. To eliminate this undesirable situation, a control system can be used between PV system and load. This control system is named as maximum power point tracker (MPPT) [2,3]. MPPT is one of the important parts of the photovoltaic system applications. MPPT is basically a dc-dc converter. This dc-dc converter can be buck type, boost type and buck-boost type depends on the application area. The fundamental idea behind the MPPT system is to ensure that the PV operates on the maximum power point of I-V curve. Fig. 1 shows the basic I-V and P-V curve of the PV array.

MPPT is controlled by MPPT algorithms. These algorithms divided into two groups: direct and indirect. In indirect methods, the operating point where PV generator operates with maximum power is estimated either measuring current, voltage and radiation values or with numerical approximations-mathematical expressions using experimental datum. In direct methods, the maximum power point is not obtained by procedures which are used in indirect methods; contrarily, the system is forced to operate at maximum power point [4].

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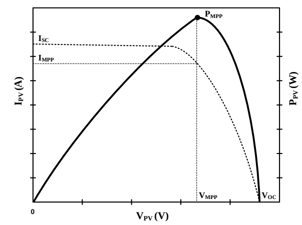


Figure 1. I-V and P-V curve of a PV array

In this paper, four commonly used MPPT algorithms (Perturbation&Observe, Incremental Conductance, Only Current Photovoltaic and Short Circuit Current) are modeled with Matlab/Stateflow. These algorithms are tested with Matlab/Simulink model and results are presented. The paper is organized as follows: Section II describes the basic background of the algorithms and modeling procedure. Section III presents the obtained test results. At last, the paper is concluded with Conclusion.

II. Bachground and Modeling

MPPT algorithms control the dc-dc converter to take the PV voltage to the maximum power point. This control is basically changing of duty-cycle of the dc-dc converter. Duty-cyle changing decision depends on the: PV current in Only Current Photovoltaic algorithm, short circuit current in Short Circuit Current algorithm, PV current and voltage in Perturbation&Observe and Incremental Conductance algorithms. Basic stand-alone PV system is depicted in Fig. 2.

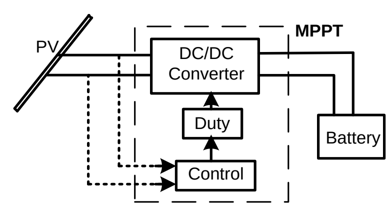


Figure 2. Basic stand-alone PV system

Control part of the MPPT in Fig. 2 is a MPPT algorithm. Control and Duty part of the MPPT system is depicted in Fig. 3 as a Matlab/Simulink model.

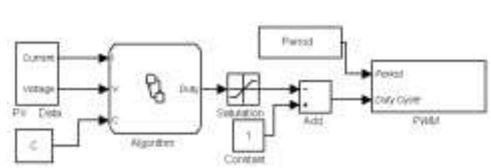
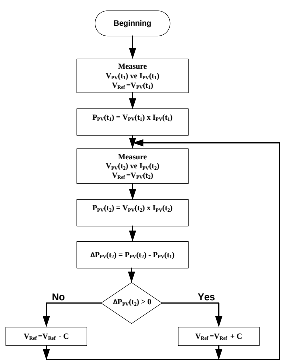


Figure 3. Matlab/Simulik model of MPPT control

Algorithm blog of the Fig. 3 is an actual control part of the MPPT system. In Fig. 3, PV current and voltage are input values and C is the step-size of the algorithm. Duty is an output value of the algorithm. Duty is converted to PWM signal.

A. Perturbation&Observe Algorithm(P&O)

P&O algorithm uses an iterative method to achieve maximum power from PV. P&O algorithm measures the power values of PV array and then compares the operation point with prior one to change the duty. If the PV power change is positive, then it changes the duty in same direction. On the other hand, if the PV power change is negative, then it changes the duty in reverse side. This duty change continues until PV power reaches the maximum power point. P&O algorithm have many simple or complex flowcharts. Fig. 4 shows a simple flowchart of algorithm and Matlab/Stateflow model.



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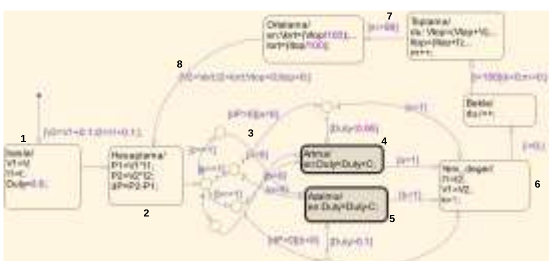

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Figure 4. P&O algorithm flowchart (a) and Matlab/Stateflow model (b)

Detailed description of Matlab/Stateflow model in Fig. 4 is given in Table 1 according to the numbers in the model.

TABLE I. P&O MODEL DESCRIPTION

No	Comment	No	Comment
1	Beginning	5	Decrease Duty
2	Calc. $P_{PV}(t_1)$, $P_{PV}(t_2)$, ΔP	6	$V_{PV}(t_1)$, $I_{PV}(t_1)$ assign.
3	Evaluate ΔP	7	Meas. $V_{PV}(t_2)$, $I_{PV}(t_2)$
4	Increase Duty	8	Go to 2

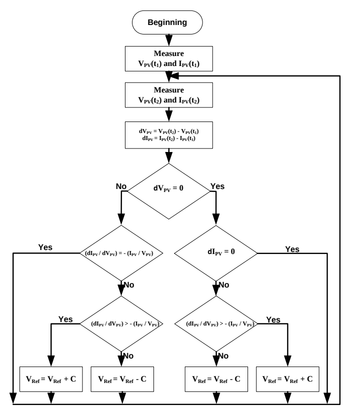
B. Incremental Conductance Algorithm(IC)

IC algorithm track the maximum power point based on the observation of conductivity by taking the instantaneous voltage and current of PV. Conductivity observation is based on the differentiation of PV power with respect to the PV voltage and setting result to zero [5]. Equation (1) and (2) give the conductivity observation methodology.

$$\frac{dP_{PV}}{dV_{PV}} = I_{PV}\frac{dV_{PV}}{dV_{PV}} + V_{PV}\frac{dI_{PV}}{dV_{PV}} = I_{PV} + V_{PV}\frac{dI_{PV}}{dV_{PV}} = 0 \quad (1)$$

$$-\frac{I_{PV}}{V_{PV}} = \frac{dI_{PV}}{dV_{PV}} \quad (2)$$

In (2), the left side of the equations is expressing the negative conductivity and the right side of the equation is expressing the incremental conductance. Fig. 5 shows flowchart of IC algorithm and Matlab/Stateflow model.



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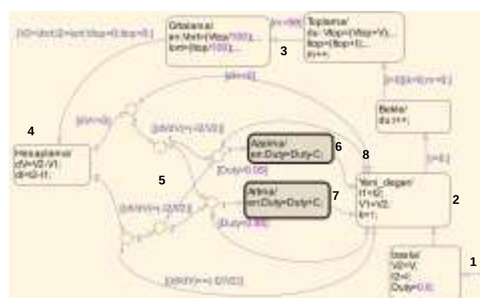


(b)

Figure 5. IC algorithm flowchart (a) and Matlab/Stateflow model (b)

Detailed description of Matlab/Stateflow model in Fig. 5 is given in Table 2 according to the numbers in the model.

TABLE II. IC MODEL DESCRIPTION

No	Comment	No	Comment
1	Beginning	5	Evalu. Conductance
2	$V_{PV}(t_1)$, $I_{PV}(t_1)$ assign.	6	Increase Duty
3	Meas. $V_{PV}(t_2)$, $I_{PV}(t_2)$	7	Decrease Duty
4	Calculate dV and dI	8	Go to 2

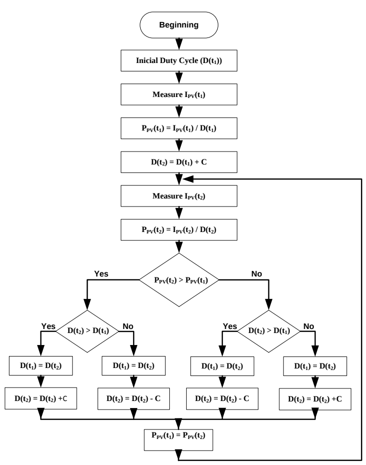
C. *Only Current Photovoltaic Algorithm(OC)*

In the P&O and IC algorithms, PV current and voltage must be measured. In the OC algorithm, the PV is forced to operate at the maximum power point by using only PV current [4],[6,7]. Nonlinear PV model can be expressed as $I_{PV} = f(V_{PV}, I_{PV})$. Then the PV voltage can be expressed as a main function of the PV current $I_{PV} = f(V_{PV})$ [8]. This function can be used in dc-dc converter equations. OC algorithm can be used with boos type or buck type dc-dc converter. Equation (3) and (4) can be obtained from boost type dc-dc converter equation.

$$P_{PV} = V_{PV} x I_{PV} = V_o x (I_{PV} x (1-D)) \qquad (3)$$

$$P_{boost} = I_{PV} x (1-D) \qquad (4)$$

In the OC algorithm, firstly PV current and PV voltage are measured and then PV power is calculated. Then duty-cycle is changed. Secondly PV current and PV voltage are measured and then PV power calculated. Thirdly PV power compares with prior one. As a result of the comparison, algorithm decides to increase/decrease the duty-cycle. This duty change continues until PV power reaches the maximum power point. Fig. 6 shows the flowchart of IC algorithm and Matlab/Stateflow model.



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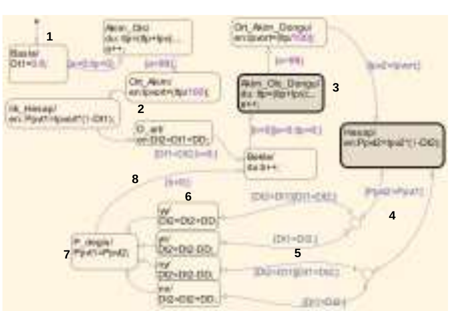

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Figure 6. OC algorithm flowchart (a) and Matlab/Stateflow model (b)

Detailed description of Matlab/Stateflow model in Fig. 6 is given in Table 3 according to the numbers in the model.

TABLE III. OC MODEL DESCRIPTION

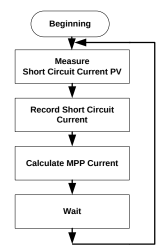
No	Comment	No	Comment
1	Beginning	5	Evaluate Duty
2	Meas. $I_{PV}(t_1)$, Calc. $P_{PV}(t_1)$	6	Incre./Decre. Duty
3	Meas. $I_{PV}(t_2)$, Calc. $P_{PV}(t_2)$	7	$P_{PV}(t_1)$ assignment
4	Evaluate $P_{PV}(t_1)$, $P_{PV}(t_2)$	8	Go to 3

D. *Short Circuit Current Algorithm(SC)*

SC algorithm depends on the linear relation between maximum power point current (I_{MPP}) and PV short circuit current (I_{SC}). The relation is actually a proportional constant. The proportional constant mainly depends on the fill factor, solar cells fabrication technology and the environmental conditions [4].

$$k = \frac{I_{MPP}}{I_{SC}} < 1 \cong Constant \qquad (5)$$

SC algorithm flowchart and Matlab/Stateflow model are depicted in Fig. 7.



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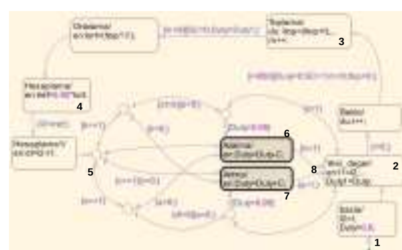

(b)

Figure 7. SC algorithm flowchart (a) and Matlab/Stateflow model (b)

Detailed description of Matlab/Stateflow model in Fig. 7 is given in Table 4 according to the numbers in the model.

TABLE IV. SC MODEL DESCRIPTION

No	Comment	No	Comment
1	Beginning	5	Evaluate I_{MPP}
2	$I_{SC}(t_1)$ assign.	6	Decrease Duty
3	Measure $I_{SC}(t_2)$	7	Increase Duty
4	Calculate I_{MPP}	8	Go to 2

III. Result and Discussions

In order to test the modeled MPPT algorithms, Matlab/Simulink model as depicted in Fig. 3 is used. Fig. 8 shows current, voltage and power variation graphs. Current and voltage as seen in Fig. 8 is used for testing algorithms. The duty variation result obtained from algorithms is depicted in Fig. 9.

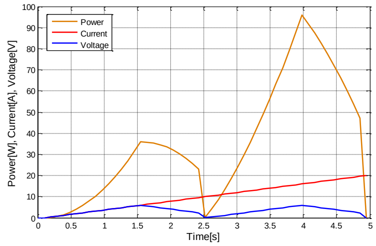

Figure 8. SC Current, voltage and power variation

Duty variations results show that all algorithms are intended to reduce the Duty value depended to current-voltage variation in Fig. 8. P&O algorithm is faster than the IC algorithm to reduce initial Duty value. IC algorithm and P&O algorithm behaviors are similar in the later stages. OC algorithm changes the initial value to the wrong direction. After the first second OC algorithm intend to reduce duty. SC algorithm intends to reduce duty after the first second. SC algorithm reduces the duty to zero periodically as shown in Fig. 9 because of the short circuit current measurement.

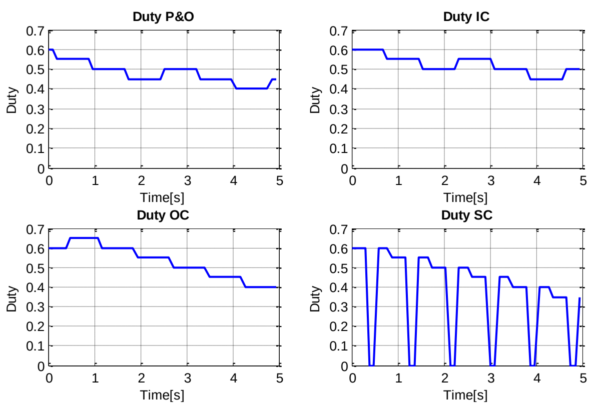

Figure 9. Duty variation result

As it can be seen in Fig. 9, P&O and IC algorithms increase the duty between 1.5-2.5 second due to the reduce in PV power. However, PV power reduce is not detected by OC and SC algorithms.

IV. Conclusion

In this paper, four commonly used MPPT algorithms (Perturbation&Observe, Incremental Conductance, Only Current Photovoltaic and Short Circuit Current) are modeled with Matlab/Stateflow. These algorithms are tested with Matlab/Simulink model and results are presented. Stateflow is a very good Tool for the modeling of MPPT algorithms. Algorithms are correctly modeled in Stateflow according to the flowcharts. Matlab/Stateflow modeling is a very simple way no matter how decision process of algorithm is difficult.

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