Performance Study of Incremental Conductance and Modified Incremental Conductance MPPT Algorithms for Photovoltaic Applications

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ABSTRACT

Solar panels have a nonlinear voltage-current characteristic, with a distinct maximum power point (MPP), which depends on the environmental factors, such as temperature and irradiation. In order to continuously harvest maximum power from the solar panels, they have to operate at their MPP despite the inevitable changes in the environment. This is why the controllers of all solar power electronic converters employ some method for maximum power point tracking (MPPT). Over the past decades many MPPT techniques have been published. In this thesis two MPPT Methods i.e. Incremental Conductance and Modified InCond methods are studied and compared.

KEYWORDS: Photovoltaic cell, MPPT, InCond, Modified Incond.

I.INTRODUCTION

Global warming and energy policies have become a hot topic on the international agenda in the last years. Developed countries are trying to reduce their greenhouse gas emissions. In this context, *photovoltaic* (PV) power generation has an important role to play due to the fact that it is a green source. The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel, the efficiency of the inverter and the efficiency of the *maximum power point tracking* (MPPT) algorithm. Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. Instead, improving the tracking of the *maximum power point* (MPP) with new control algorithms is easier, not expensive and can be done even in plants which are already in use by updating their control algorithms, which would lead to an immediate increase in PV power generation and consequently a reduction in its price.

MPPT algorithms are necessary because PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum [1]. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained.

In this thesis the Incremental Conductance method is studied and analyzed in depth. After that improvement to the InCond algorithm i.e. Modified InCond algorithm is suggested to succeed in the MPP tracking under conditions of changing irradiance.

II.SOLAR CELL

The solar cell can be represented by the electrical model shown in Figure-1. Its current voltage characteristic is expressed by the following equation (1):

$$I = I_L - I_0\left(e^{\frac{q(V-IR_S)}{AkT}} - 1\right) - \frac{V - IR_S}{R_{SH}} \quad (1)$$

where *I* and *V* are the solar cell output current and voltage respectively, *I0* is the dark saturation current, *q* is the charge of an electron, *A* is the diode quality (ideality) factor, *k* is the Boltzmann constant, *T* is the absolute temperature and *RS* and *RSH* are the series and shunt resistances of the solar cell. *RS* is the

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resistance offered by the contacts and the bulk semiconductor material of the solar cell. The origin of the shunt resistance *RSH* is more difficult to explain. It is related to the non ideal nature of the p–n junction and the presence of impurities near the edges of the cell that provide a short-circuit path around the junction [7]. In an ideal case *RS* would be zero and *RSH* infinite. However, this ideal scenario is not possible and manufacturers try to minimize the effect of both resistances to improve their products.

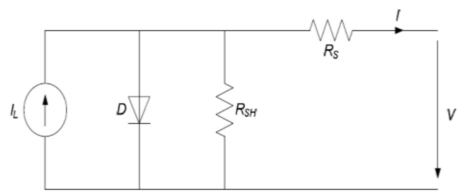

Figure 1 - Equivalent circuit of a solar cell.

Sometimes, to simplify the model, as in [3], the effect of the shunt resistance is not considered, i.e. *RSH* is infinite, so the last term in (1) is neglected. A PV panel is composed of many solar cells, which are connected in series and parallel so the output current and voltage of the PV panel are high enough to the requirements of the grid or equipment. Taking into account the simplification mentioned above, the output current-voltage characteristic of a PV panel is expressed by equation (2), where *np* and *ns* are the number of solar cells in parallel and series respectively.

$$I \approx n_p I_L - n_p I_0 \left(e^{\frac{q(V-IR_S)}{AkTn_s}} - 1 \right)$$

III.OPEN CIRCUIT VOLTAGE, SHORT CIRCUIT CURRENT AND MPP

Two important points of the current-voltage characteristic must be pointed out: the open circuit voltage *VOC* and the short circuit current *ISC*. At both points the power generated is zero. *VOC* can be approximated from (1) when the output current of the cell is zero, i.e. *I*=0 and the shunt resistance *RSH* is neglected. It is represented by equation (3). The short circuit current *ISC* is the current at *V* = 0 and is approximately equal to the light generated current *IL* as shown in equation (4).

$$I_{SC} \approx I_L \qquad V_{OC} \approx \frac{AkT}{q} ln\left(\frac{I_L}{I_0} + 1\right)$$

(3)

(4)

The maximum power is generated by the solar cell at a point of the current-voltage characteristic where the product *VI* is maximum. This point is known as the MPP and is unique, as can be seen in Figure 2, where the previous points are represented

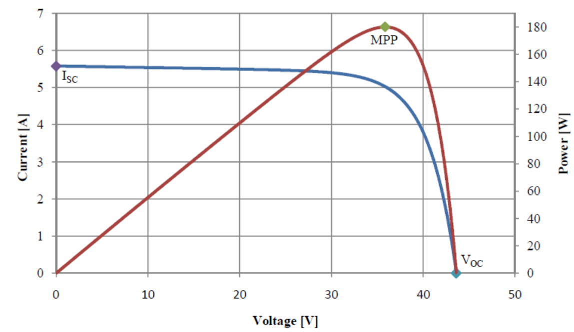

Figure-2 important points in the characteristic curves of a solar panel.

IV.INCREMENTAL CONDUCTANCE ALGORITHM

The incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right, as can be seen in Figure-3

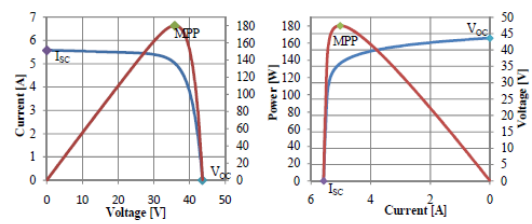

Figure 3- PV panel characteristic curves.

- $\Delta V/\Delta P = 0$ $(\Delta I/\Delta P = 0)$ at the MPP
- $\Delta V/\Delta P > 0$ $(\Delta I/\Delta P < 0)$ on the left
- $\Delta V/\Delta P < 0$ $(\Delta I/\Delta P > 0)$ on the right

By comparing the increment of the power vs. the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined. A scheme of the algorithm is shown in Figure 4. Similar schemes can be found in [6],

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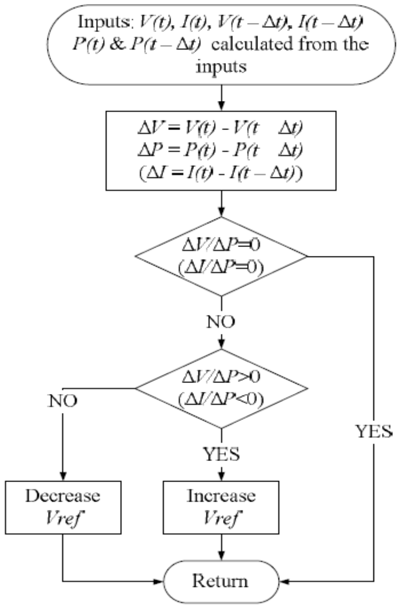

Figure 4 - Incremental Conductance algorithm

In InCond scheme, how fast the MPP is reached depends on the size of the increment of the reference voltage. The drawbacks of this techniques are mainly two. The first and main one is that they can easily lose track of the MPP if the irradiation changes rapidly [1], [5]-[2]. In case of step changes they track the MPP very well, because the change is instantaneous and the curve does not keep on changing. However, when the irradiation changes following a slope, the curve in which the algorithm based changes continuously with the irradiation, as can be seen in Figure-5, so the changes in the voltage and current are not only due to the perturbation of the voltage. As a consequence it is not possible for the algorithms to determine whether the change in the power is due to its own voltage increment or due to the change in the irradiation.

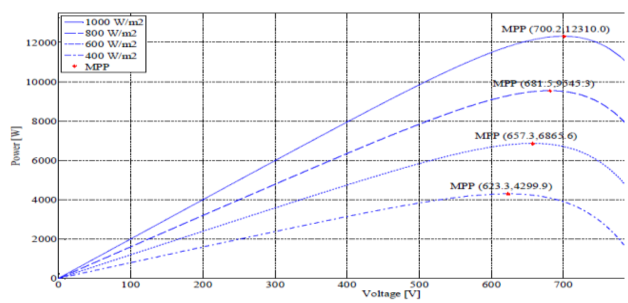

Figure 5 – P-V curve depending on the irradiation.

The other handicap of this method is the oscillations of the voltage and current around the MPP in the steady state [1] and [8]. This is due to the fact that the control is discrete and the voltage and current are not constantly at the MPP but oscillating around it. The size of the oscillations depends on the size of the rate of change of the reference voltage. The greater it is, the higher is the amplitude of the oscillations. However, how fast the MPP is reached also depends on this rate of change and this dependence is inversely proportional to the size of the voltage increments. The traditional solution is a trade off: if the increment is small so that the oscillations decrease, then the MPP is reached slowly and vice versa, so a compromise solution has to be found.

V.SIMULATION MODEL OF INCOND METHOD

The model proposed here was developed in Matlab®/Simulink® and consists of a model of the PV array, the DC-link capacitor and a controlled current source, which replaces the power converter. The MPPT Control block generates the reference voltage using the MPPT algorithm shown in Figure-4. This model is depicted in Figure-6. The model of the PV array used in this work was designed following the references [9] and [10].

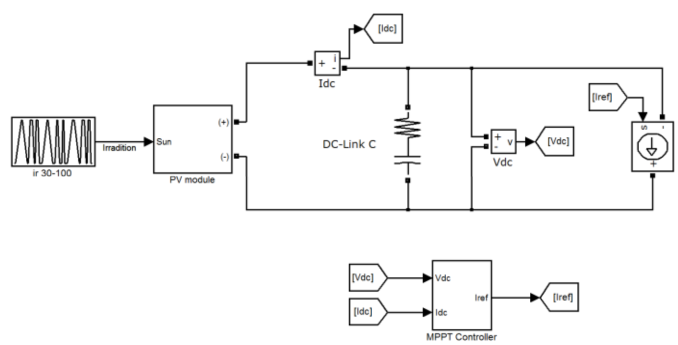

Figure 6 - Model used for simulations.

The parameters of the system used in all the simulations performed in this thesis are as follows:

Solar panel characteristics at STC:

- Open circuit voltage: 900 V
- Voltage at MPP: 700.2 V
- Short circuit current: 20 A
- Current at MPP: 17.6 A

DC-Link Capacitor:

- Capacitance: 700 μF
- ESR: 1 mΩ

Sampling frequency:

- MPPT algorithm: 25 Hz
- *V* and *I* measurements: 20 kHz

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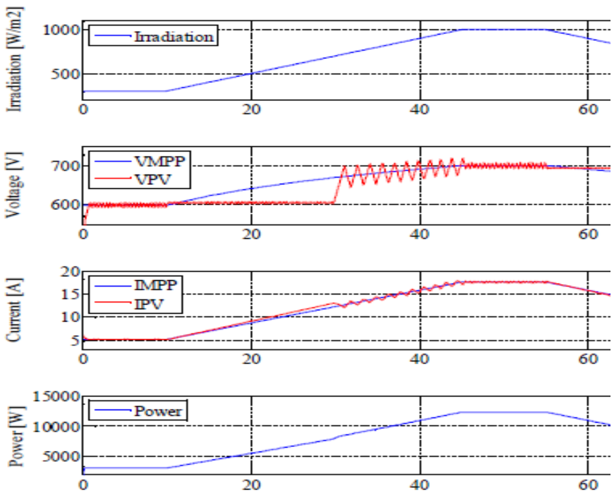

Figure 7- Voltage, current and power under irradiation ramps

VI.MODIFIED INCREMENTAL CONDUCTANCE ALGORITHM

From the previous case under irradiation ramps, it is obvious that with the algorithm the voltage from the PV panel is far from the MPP voltage. Moreover, the algorithm may even move the DC voltage in the wrong direction. Interestingly, the current tracks closely the MPP current and in the correct direction. The same can be said about the power, as can be seen in Figure 6. This is due to the fact that the current of the PV array is directly proportional to the irradiation. For this reason, when the irradiation varies following a slope the PV current has a similar behavior. In theory, if the current changes linearly, for a given (constant) sampling frequency, there should be a specific optimal current increment. The power also changes in the same direction as the current does. When the algorithm gets confused, the current and power do not change smoothly, but nevertheless they can be used to determine the direction of the change of the MPP. If the irradiation is increasing following a slope, both the current and power increase and vice versa: if the current decreases, then the current and power decrease. The new flow chart for InCond method is depicted in Figure-8.

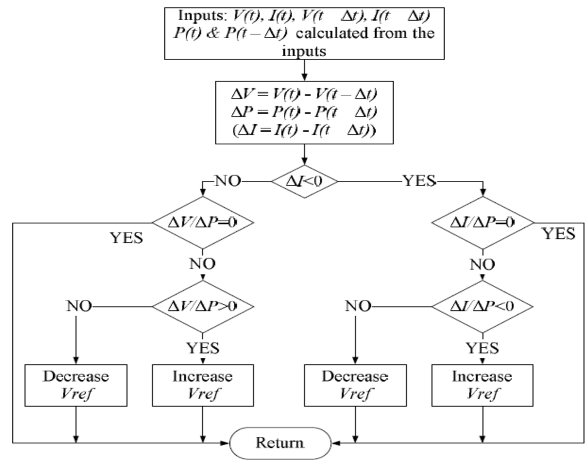

Figure 8 - New flowchart of the InCond algorithm.

VII.SIMULATION MODEL OF MODIFIED INCOND METHOD

The model proposed here was developed in Matlab®/Simulink® and consists of a model of the PV array, the DC-link capacitor and a controlled current source, which replaces the power converter. The MPPT Control block generates the reference voltage using the MPPT algorithm shown in Figure-8. This model is depicted in Figure-6. The model of the PV array used in this work was designed following the references [9] and [10].After this modification, the InCond algorithm is also capable of tracking the MPP correctly under changing irradiance. It can be shown in Figure-9

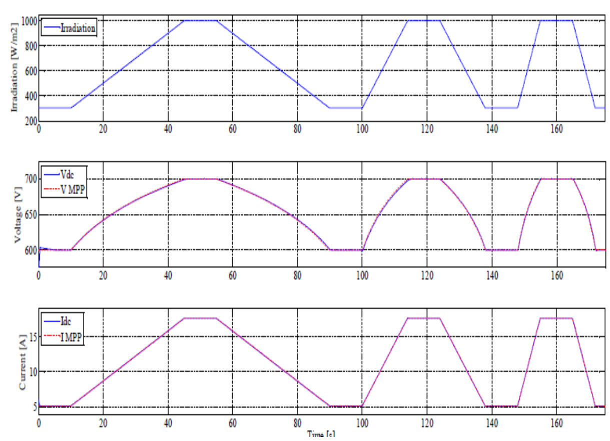

Figure 9- Voltage and current under irradiation ramps

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VIII.CONCLUSION

In this thesis first the InCond Algorithm was studied and analyzed. For testing purposes, a simplified model of the PV system was developed. In this model, the power converter was replaced with a controlled current source. This allowed long enough simulations. After that modifications to the traditional InCond algorithm was proposed, which allow the hill-climbing algorithms to track the MPP even under changing irradiation and adapt the increment in the reference voltage to the operating point, as the variation of the MPP voltage is not linear. Finally, taking into account above the results, it can be concluded that the best algorithm is the modified InCond Algorithm.

REFERENCES

[1] N. Femia, G. Petrone, G. Spagnuolo, M. Vitelli, "Optimizing sampling rate of P&O MPPT technique," in *Proc. IEEE PESC,* 2004, pp. 1945- 1949.

[2] K.H. Hussein, I. Muta, T. Hoshino, M. Osakada, "Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions," *IEE Proceedings on Generation, Transmission and Distribution*, vol. 142, no. 1, pp. 59-64, Jan 1995.

[3] G. M. S. Azevedo, M. C. Cavalcanti, K. C. Oliveira, F. A. S. Neves, Z. D. Lins,"Evaluation of maximum power point tracking methods for grid connected photovoltaic systems," in *Proc. IEEE PESC*, 2008, pp. 1456-1462.

[4] P. A. Lynn, *Electricity from Sunlight: An Introduction to Photovoltaic's*, John Wiley Sons, 2010, p. 238

[5] D. Sera, T. Kerekes, R. Teodorescu, F. Blaabjerg, "Improved MPPT Algorithms for Rapidly Changing Environmental Conditions," in *Proc. 12th International Conference on Power Electronics and Motion Control*, 2006, pp. 1614-1619.

[6] T. Esram, P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439-449, June 2007.

[7] P. A. Lynn, *Electricity from Sunlight: An Introduction to Photovoltaic's*, John Wiley & Sons, 2010, p. 238.

[8] W. Xiao, W. G. Dun ford, "A modified adaptive hill climbing MPPT method for Photovoltaic power systems," in *Proc. IEEE PESC*, 2004, pp. 1957-1963.

[9] J. A. Gow, C. D. Manning, "Development of a photovoltaic array model for use in power electronics Simulation studies," *IEE proceedings on Electric Power Applications*, vol. 146, no. 2, pp. 193-200, Mar 1999.

[10] F. Khan, S.N. Singh, M. Husain, "Determination of diode parameters of a silicon solar cell from variation of slopes of the I-V curve at open circuit and short circuit conditions with the intensity of illumination", *Semiconductor Science and Technology*, vol. 25, no. 1,pp. 015002, Jan. 2010

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