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Two combined model MPPT algorithms for stand alone photovoltaic systems

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Abstract - *Maximum Power Point Trackers (MPPT's) play an important role in stand alone photovoltaic systems. MPPT's find and maintain operation at the maximum power point, using an MPPT algorithm. Many MPPT algorithms have been proposed in the literature. The MPPT techniques using microprocessors are favored because of their flexibility and compatibility with different PV module. The efficiency of these MPPT algorithms is drops in cases of rapidly changing atmospheric conditions. The incremental conductance solves this problem. In the other way, we find that the constant voltage algorithm is the simplest and is more effective than the incremental conductance in case of low solar irradiance condition. This paper combines the two models MPPT control algorithm, the constant voltage and the incremental conductance under different solar irradiance levels. Firstly, a novel model is proposed to predict the PV module performance for engineering applications and compared with the Walker model. A MSX60 PV, BPSX150 PV and PB585 PV modules are selected to proof the performance of the proposed model. Next, the combined two model MPPT algorithm is applied at various irradiations solar. Finally, a model of Cuk converter is built in order to verify the performance of proposed MPPT algorithm.*

Résumé - *La poursuite du point de puissance maximale (MPPT) joue un rôle important dans le système photovoltaïque autonome. Ce point trouvé est atteint en utilisant un algorithme MPPT. Plusieurs algorithmes de la poursuite du point de puissance maximale 'MPPT' sont proposés dans la littérature. Les techniques, qu'utilisent les microprocesseurs sont favorisées par sa flexibilité et la comptabilité avec différents modules PV. Le rendement de ces modules chute dans le cas des variations atmosphériques rapides. L'algorithme de l'incrémentation de la conductance résout ce problème. D'autre part, on trouve que la méthode de la tension constante est plus simple et plus efficace que la méthode de l'incrémentation de la conductance dans le cas de faible éclairement. Cet article combine les deux modèles de contrôle du tracking du point de puissance maximale, l'incrémentation de la conductance et la méthode de tension constante pour différents niveaux d'éclairement. Premièrement, un nouveau modèle est proposé pour prédire la performance du module PV et comparer avec le modèle de Walker. Les modules MSX60 PV, BPSX150 PV et PB585 PV sont sélectionnés pour prouver la performance du modèle proposé. Puis, le modèle combine les deux algorithmes du suiveur du point de puissance maximum, il peut être appliqué pour les différents éclairements. Enfin, un modèle de convertisseur Cuk est réalisé pour vérifier la performance de l'algorithme proposé.*

Keywords: PV Module model - MPPT algorithm – Modeling – Simulation - Incremental conductance - Constant voltage algorithm.

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1. INTRODUCTION

Solar energy is one of the important renewable sources, as opposed to conventional non renewable resources such as fossil fuels. The main applications of photovoltaic (PV) systems are in stand-alone mode such as water pumping, domestic and street lighting a grid connected configuration.

As known from a power voltage curve of a solar panel, there is an optimum operating point such that the PV panel delivers the maximum possible power to the load. The maximum operating point changes with atmospheric conditions (temperature and solar irradiance). Therefore, on line tracking of the maximum power point of a PV array is an essential part of any successful PV system. To obtain the maximum power from PV array, a maximum power point tracker (MPPT) is applied.

A variety of MPPT methods are developed. The methods vary in implementation complexity, sensed parameters, required number of sensors, convergence speed and cost [1]. Jancale *et al.* [2] proposed a microcontroller to control the duty cycle of a boost converter with pulse width modulation (PWM). Azab [3] used an hysteresis band to control the operation of a buck chooper. A Boost converter based MPP tracking using sliding mode control is employed by Ateaga *et al.* [4].

Another approach is based on fuzzy logic and neural network control [5]. Most of maximum power point tracker are based on the perturb and observe algorithm and incremental conductance [5, 6]. A comparative study of MPPT based in their efficiencies is presented in [7] but in [8] the MPPT algorithms are compared under the energy production and cost evaluation.

In this paper, a novel model and simulation of MSX60PV, BPSX150PV and PB585PV are selected. A comparative study with a Walker model is done. Next, a combined two model MPPT control is discussed and finally, the mode of Cuk converter is constructed with resistive load using Matlab/Simulink.

2. PV MODULE MODELLING

A simplified model with acceptable precision is used to estimate the actual performance of PV modules under varying operating conditions. Five parameters (α, β, δ, n_{MPP} and R_s) are introduced to take account for all the non linear effects of the environmental factors on PV module performance. The maximum power output delivered by the PV module is given by [9]:

$$P_{max} = F \times V_{oc} \times I_{sc} \tag{1}$$

The short circuit current, I_{sc}, can be considered equivalent to the photocurrent proportional to the irradiation solar. This model added a power law having exponent (α). It's introduced to account for the non linear effect that the photocurrent depends on. So the short circuit current can be simply calculated by:

$$I_L = I_{sc} \times \left(G / G_0\right)^{\alpha} \tag{2}$$

G and G_0 are the solar irradiance and standard solar irradiance, (W/m^2).

Take account the effect of temperature, the open circuit voltage V_{oc}, at any given conditions can be described by:

$$V_{oc} = \frac{V_{oc0}}{1+\beta\times\ln(G_0/G)} \times \left(\frac{T_0}{T}\right)^{\delta} \tag{3}$$

Where,

V_{oc} : Open circuit voltage of the PV cell under standard solar irradiance.

β : PV module technology specific-related dimensionless coefficient.

δ : Exponent considering all the non linear temperature voltage effects.

Finally, the fill factor, F, expression is given by:

$$F = F_0 \times \left(1 - \frac{R_s}{V_{oc}/I_{sc}}\right) \tag{4}$$

Where ,

F_0 is the fill factor of the ideal PV without resistive effects. R_s : Series resistance.

2.1 Parameters estimation procedure

Under two different solar irradiance (G_0, G_1) and two PV module temperature (T_0, T_1), a limited number of basic tests are needed: short circuit current, open circuit voltage, maximum power point current I_{MPP} and voltage V_{MPP} of the PV module. These data are normally available from the manufactures. The parameters described above can be determined by the following procedure [10].

The parameter α is given by:

$$\alpha = \frac{\ln(I_{sc0}/I_{sc1})}{\ln(G_0/G_1)} \tag{5}$$

While I_{sc0} and I_{sc1} are the short circuit current of the PV module under radiation intensity G_0 and G_1.

In order to calculate the parameter β, the PV module temperature is assumed to be constant:

$$\beta = \frac{(V_{oc0}/V_{oc1}) - 1}{\ln(G_0/G_1)} \tag{6}$$

V_{oc0} and V_{oc1} are the open circuit voltage of the PV module under radiation intensity of G_0 and G_1.

But the parameter δ is calculated when the solar irradiance remains stable and the PV module temperature changes from T_0 to T_1:

$$\delta = \frac{\ln(V_{oc0}/V_{oc1})}{\ln(T_0/T_1)} \tag{7}$$

The assumption of a constant ideality factor is commonly used. In Walker model [11] for MSX60PV module an estimate value of 1.3 is suggested as initial value for normal operation. Akihiro [12] estimated a value of 1.62 for BPSX150PV module and a value of 1.0 is proposed in the datasheet of PB585PV. But this assumption is inaccurate because the PV systems are usually equipped with a maximum power point tracker, so that it's reasonable to determine the ideality factor at the maximum power point (n_{MPP}), which is given by:

$$n_{MPP} = \frac{(V_{MPP} + I_{MPP} \times R_s)}{V_{oc} + V_t \times \ln\left(I_{sc} - I_{MPP}/I_{sc}\right)} \tag{8}$$

with V_t is thermal voltage.

The last parameter is the series resistance which has a significant effect on the performance of a PV module. In this study and for the simplicity, the calculation of the series resistance is done as described in [11].

3. MPPT ALGORITHMS

3.1 Constant voltage algorithm

This method is based on the observation that MPP voltage (V_{MPP}) has almost a linear relation with open circuit voltage (V_{oc}) of the panel:

$$V_{MPP} = K_{cv} \times V_{oc} \tag{9}$$

The PV panel is locked at the reference voltage given by equation (9). The open circuit voltage is required to determine the MPP voltage can be measured by disconnecting load from the PV panel after regular intervals. The measured values of V_{oc} and K_{cv} are stored and used the determination of PV panel voltage.

To operate the panel at MPP, the actual PV panel voltage is compared with the reference voltage which corresponds to the MPP voltage. The error signal is used to change the duty cycle of DC/DC converter, interface between the PV panel and the load [13]. Although this method is extremely simple, it's difficult to choose the optimal value of the constant K_{cv} The literature reports success with K_{cv} values ranging from 73 à 80 % [14].

The constant voltage control ' CV ' can be easily implemented. However, its MPPT tracking efficiency is low relative to those of other algorithms. Reasons for this include the aforementioned error in the value of K_{cv} and the fact that measuring the open circuit voltages a momentary interruption of PV power.

3.2 Incremental conductance algorithm

The incremental conductance algorithm ' Inccond ' is derived by differentiating the PV array power with respect to voltage and setting the result equal to zero [1]:

$$\frac{dP}{dV} = I + V \times \left.\frac{dI}{dV}\right|_{=0} \qquad \text{(at the MPP)} \tag{10}$$

Rearranging equation (10) gives:

$$dI/dV = -I/V \tag{11}$$

If the operating point is the left side of the MPP-

$$dI/dV > -I/V \tag{12}$$

If the operating point is the left side of the MPP-

$$dI/dV < -I/V \tag{13}$$

Note that the left side of the Eqs 11-13 represents incremental conductance of the PV module and the right side of the equation represents its instantaneous conductance.

The incremental conductance algorithm starts with measuring the present values of PV module voltage and current. Then, it calculates the incremental changes, dI and dV, using the present values of voltage and current.

The main check is carried out by comparing dI/dV against $-I/V$, and according to the results of this check, the control reference signal V_{ref} will be adjusted in order to move the array terminal voltage towards the MPP voltage. When the above incremental was tested, we noted that the condition $dI/dV = 0$ seldom occurred because of the approximation made in the calculation of dI and dV.

However, this condition can be detected by allowing a small marginal error (E) in the above comparison and the value of E depends on the required sensitivity of MPP.

3.3 Combined algorithm

Our contribution is to combine the two MPPT control described above. It's important to observe that when the PV panel is in low solar irradiance condition, the constant voltage method is more effective than the incremental conductance algorithm. Other way, under rapidly changing atmospheric condition, the incremental conductance algorithm gives a good performance.

4. DC/DC CONVERTER

The goal of the MPPT is to match the impedance of load to the optimal impedance of a PV module. For this purpose, a DC/DC converter has to be connected between PV and the load.

In our design we adopted a Cuk converter. It can provide the output voltage that is higher or lower than the input voltage and on the other hand, the input current of the Cuk converter is continuous and they can draw a ripple free current from a PV array that is important for efficient MPPT. Figure 1 shows a circuit diagram of the basic Cuk converter. It can provide a better output current characteristic due to the inductor on the output stage.

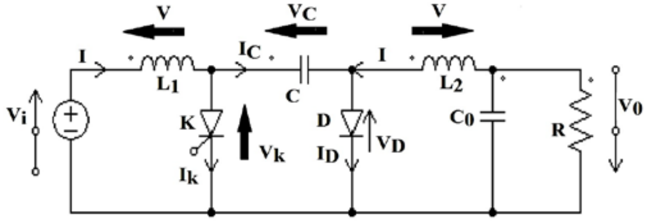

Fig. 1: Circuit diagram of the basic Cuk converter

The output voltage is given by [15]:

$$V_0 = V_i \times \left(\frac{D}{1-D} \right) \tag{14}$$

Where, D is the duty cycle.

The input impedance of the converter is described by the following equation:

$$R_{in} = \left(\frac{1-D}{D} \right)^2 \times R_{load} \tag{15}$$

The impedance seen by PV is the input impedance of the converter. By changing the duty cycle, the value R_{in} can be matched with that of optimum load, which is defined by the coordinates of the MPP [12, 15].

$$R_{in} = V_{MPP} / I_{MPP} \tag{16}$$

5. SIMULATION RESULTS

In the first step, the parameters estimation results for the selected PV modules used in this study are shown in **Table 1**. We can see that has not a large difference between the values of ideality factors for the novel and Walker models.

All parameters of the novel model are found directly in manufacturer's datasheet. Thus, once the solar irradiance and the PV temperature are known, the power output of the PV system can be predicted easily as indicate in equation (1).

For these reasons, the novel model is more accuracy and efficient than the Walker model.

Table 1: Parameters estimations for the different PV module

PV Types	α	β	δ	η_{MPP}	R_s
MSX60	0.99	0.063	0.17	1.46	8.0
BPSX150	1	0.066	0.13	1.50	5.1
PB585	1	0.093	0.44	1.10	0.4

For the above modeled MSX60 PV module, the maximum power point tracking is done with both the incremental conductance and constant voltage algorithms by using simulation Matlab/Simulink. Moreover, to evaluate the performance of the proposed MPPT, the PV is exposed to different solar irradiance and temperature is used at different operating conditions.

Firstly, the ' Inccond ' method is based on the principle of impedance matching between the PV source and the effective load across it. In this step, we adopted a boost and Cuk converters as DC transformer which can match the module optimum load by changing its switching duty as a function of the atmospheric conditions ($G = 200$ W/m^2 to 1000 W/m^2 and $T = 25$ °C), as illustrates in figure 2. It's important to observe that the Cuk converter presents a good performance than the boost.

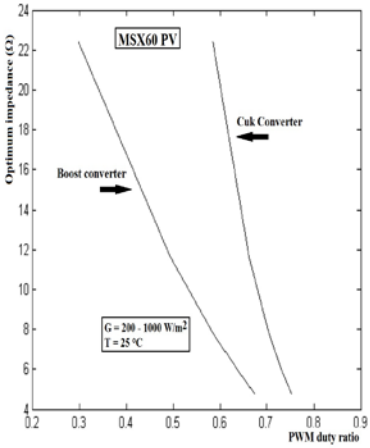

Fig. 2: Duty ratio of the boost and Cuk converters to match at fixed load

In the ' CV ' algorithm, it's difficult to choose the optimal values of the constant K_{cv} . Figure 3, shows the actual K_{cv} values required for a given BPSX150 PV module over a temperature of 0 - 50 °C and solar irradiance levels from 200 W/m^2 to 1000 W/m^2. It's indicating that the ratios K_{cv} is not constant but in fact depends on temperature and solar irradiance.

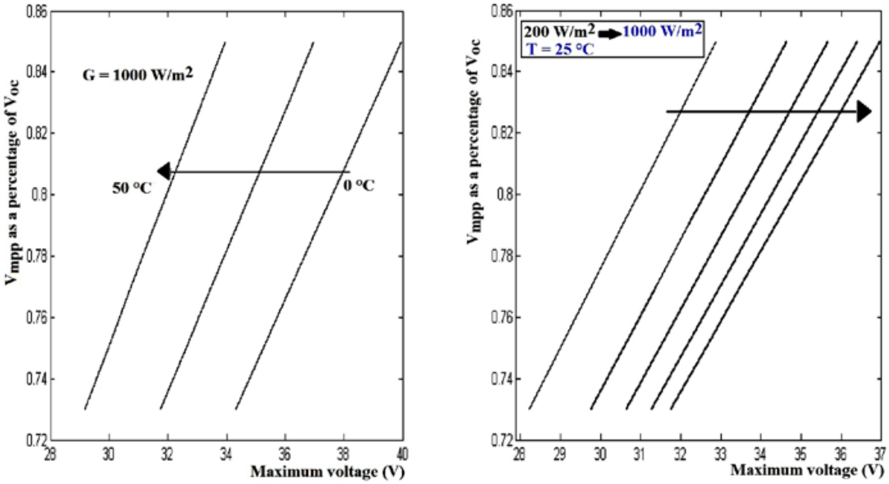

Fig. 3: V_{MPP} as a percentage of V_{oc} as
function of temperature and solar irradiance

In order to test the MPPT techniques, we used different type of solar irradiance and we assume that the K_{cv} of ' CV ' algorithm is nearly constant (≈ 0.76) [14]. So we adopted this value in the next simulation.

When the solar irradiance change gradually, for two step inputs, the first varies between (200 W/m^2 to 1000 W/m^2) and second between (800 W/m^2 to 400 W/m^2). The two MPPT algorithms track the new values of maximum power. In each case, the power extracted from the PV is well controlled as shown in figure 4 and figure 5 respectively.

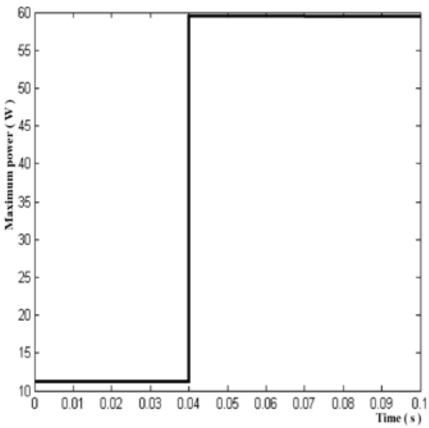

Fig. 4: Power generated by the MSX60 PV module in the case of the first step

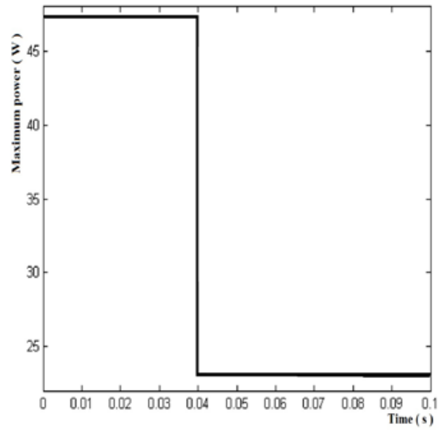

Fig. 5: Power generated by the MSX60 PV module in the case of the second step

While the solar irradiance and temperature change rapidly and randomly as illustrated in figure 6. For both algorithms, the deviation of operating points from the MPP’s obvious when compared to the results of a first case.

Between two algorithms, the ‘ Inccond ’ algorithm is supposed to outperform the ‘ CV ’ algorithm under rapidly changing atmospheric conditions.

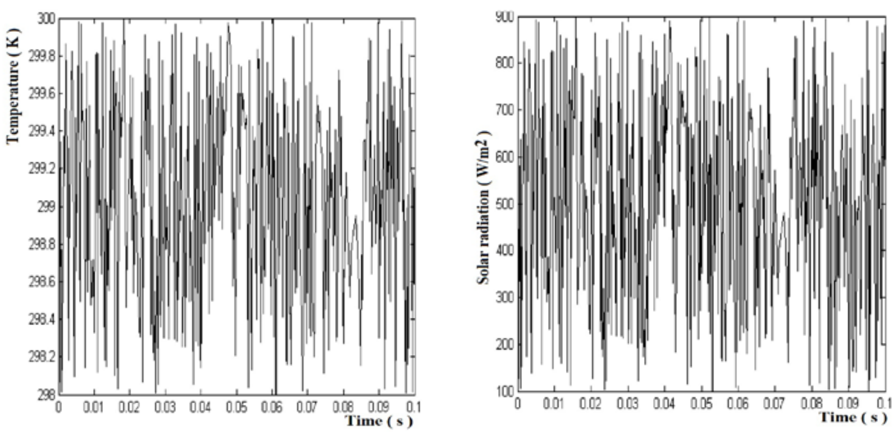

Fig. 6: Solar irradiance and temperature variations

For this reason, the two modes MPPT controls are combined to make the result more accuracy. So, if the irradiance solar is lower 30 % of the nominal irradiance solar, the ‘ CV ’ algorithm is used. Other way, the ‘ Inccond ’ algorithm is adopted.

The control signal and maximum power tracking are shown in figure 7 and figure 8.

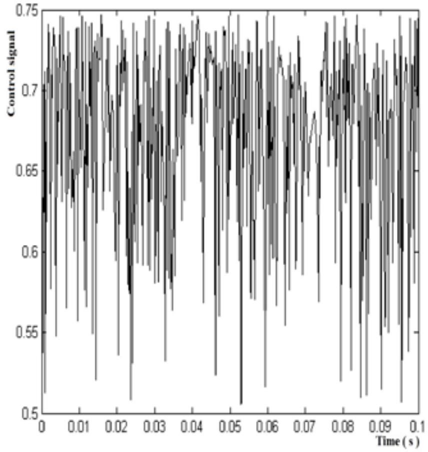

Fig. 7: Control signal of cuk converter

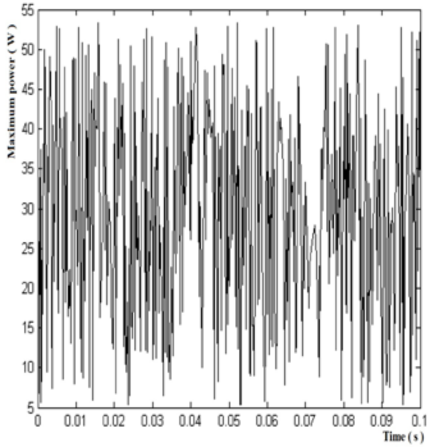

Fig. 8: Power generated by the MSX60 PV module

5. CONCLUSION

In this paper, two MPPT control algorithms, constant voltage ‘ CV ’ and incremental conductance ‘ Inccond ’, are discussed. Based on the results presented, the following conclusions may be stated:

- The ‘ CV ’ algorithm is easy to implement and sometime combined together with other MPPT techniques.
- In low solar irradiance conditions, the ‘ CV ’ algorithm is used.
- The ‘ Inccond ’ algorithm requires two measurements: a measurement of the voltage and a measurement of the current.
- Under rapidly changing atmospheric conditions, the ‘ Inccond ’ is adopted.
- The two model MPPT control algorithm combines ‘ CV ’ and Inccond method is presented. Mathematical models were used to simulate the PV module in the evaluation of the algorithm performances under randomly varying atmospheric conditions. A cuk converter as a transformer was controlled using the combined MPPT control to maximize PV power flow to a load. The results show the successful operation of the combined MPPT control and aims to integrate in the stand alone photovoltaic systems.

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