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A New Adaptive Step Size IC MPPT Controller for High-Performance of PV Systems

[1]Sabir Messalti and [1, 2]Abdelghani Harrag
[1]Department of Electrical Engineering, Faculty of Technology, M'sila University, M'sila, Algeria
[2]CCNS Laboratory, Department of Electronics, Faculty of Technology, Setif University, Setif, Algeria

Abstract: In this study, a new Maximum Power Point Tracking (MPPT) controller for PV systems performances improvement has been proposed. The proposed method uses the Incremental Conductance (IC) MPPT algorithm with adaptive duty cycle step. The classical IC MPPT algorithm is widely used in many applications due to its simplicity. However, IC MPPT is characterized by several low performance factors (high ripple, response time and oscillation around the MPP affecting the convergence speed, prone to failure especially when high changes in irradiance). To face the aforementioned drawbacks, modified IC MPPT algorithm with variable step size has been developed in this study. The proposed method was developed and tested successfully using a boost converter connected to a Sun Module (SW) 240 W. Simulations are provided in several aspects using MATLAB/Simulink Model for different atmospheric conditions. A comparative study between the proposed variable step size and fixed step size IC MPPT method has been accomplish. Results and analysis are presented in which many contribution have been demonstrated in terms of response time, MPPT tracking, reducing of oscillation.

Key words: Incremental Conductance (IC) MPPT algorithm, variable step size MPPT, photovoltaic cell model, accomplish, aspects, converter

INTRODUCTION

The rapid development of modern lifestyles requires more and more efficient energy sources which a large part of global energy production comes the conventional energy sources. However, the use of these sources produces the greenhouse emissions and therefore an increase in the warming and pollution. The additional dilemma is that excessive consumption of natural resources reduces the stock reserves of this type of energy in a hazardous manner for future generations and has raised concerns over the energy security. Hence, the problem of energy is more and more aggravating. For these reasons, many countries have reoriented their energy strategies to new forms of green energy called "renewable energy" that are currently too expensive and relatively inefficient. Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides, geothermal heat and various forms of biomass. These resources are renewables and can be naturally replenished continuously. This energy cannot be exhausted and is constantly renewed. Among the renewable energy sources, Photo Voltaic (PV) energy is an attractive source of energy and it is one of the most important renewable energy sources that has been increasing worldwide year by year, it has been continuously growing at a rapid race over the recent years (Loukriz *et al*., 2016; Rekioua and Matagne, 2012; Goetzberger and Hoffmann, 2005; Bajpai and Dash, 2012; Harrag and Messalti, 2015). The Photo Voltaic (PV) system technologies are rapidly expanding and have increasing roles in electric power technology, since, it exhibits many merits such as cleanness, simple in design requiring very little maintenance and no noise, abundant and available almost everywhere unlike other types such as wind turbines, biomass, geothermal, waves, etc. (Loukriz *et al*., 2016; Rekioua and Matagne, 2012; Goetzberger and Hoffmann, 2005). The main advantages of photovoltaic systems are summarized by the following: the photovoltaic energy is abundant and free, it can reduce the pollutant emissions and preserve the natural resources, the photovoltaic processes are completely self-contained, the photovoltaic energy may be combined with other power sources to increase system reliability, etc.

Although, the large number of afore mentioned Photovoltaic advantages, it still presents some draw backs comparing to conventional energy resources,

Corresponding Author: Sabir Messalti, Department of Electrical Engineering, Faculty of Technology, M'sila University, M'sila, Algeria

especially, its low conversion efficiency which is only in the range of 9-17%, high fabrication cost and nonlinear characteristics. Therefore, the energy harvesting at maximum efficiency is not simple enough (Loukriz *et al*., 2016; Rekioua and Matagne, 2012; Goetzberger and Hoffmann, 2005). To overcome these problems, maximum power point tracking control algorithm is required to adjust continuously the power interfaces to obtain the maximum power available from a PV array at any given time under variable conditions (insolation, shading, temperature, load). There is a unique operating point on the array's Power Voltage (PV) curve called the Maximum Power Point (MPP) where the power generation is maximum. MPPT controllers operates by sensing the current and voltage of the PV array; the power is calculated and accordingly the duty cycle of the converter is adjusted to match the Maximum Power Point (MPP) (Harrag and Messalti, 2015; Hiyama *et al*., 1995a, b; Scarpa *et al*., 2009; Bhatnagar and Nema, 2013; Eldahab *et al*., 2014; Femia *et al*., 2005).

In the last decade, enormous number of MPPT techniques have been proposed and improved continuously. These methods include Perturbation and Observation (P&O) algorithm (Rekioua and Matagne, 2012; Eldahab *et al*., 2014; Femia *et al*., 2005; Piegari and Rizzo, 2010), Incremental Conductance (IC) method (Tey and Mekhilef, 2014; Li and Wang, 2009; Safari and Mekhilef, 2011) and Hill Climbing (HC) (Wiodong and Dunford, 2004; Esram and Chapman, 2007; De Brito *et al*., 2013), neural network, fuzzy logic, Particle Swarm Optimization (PSO), Genetic algorithms (Harrag and Messalti, 2015; Letting *et al*., 2012; Hiyama *et al*., 1995). Fractional Open-Circuit Voltage (FOCV), Fractional Short-Circuit Current (FSCC) (Masoum *et al*., 2002; Noguchi *et al*., 2000; Hart *et al*., 1984). In addition, many combined or hybrid methods have been developed such as Genetic Algorithm-Neural Networks (GA-ANN) (Ramaprabha *et al*., 2011) and Genetic Algorithm-Fuzzy Logic Controller (GA-FLC) (Larbes *et al*., 2009). Among all the previous MPPT strategies, the P&O, IC and Hill climbing algorithms are widely employed due to easy implementation and high tracking accuracy. However, the performance depends essentially to the fixed step size, a faster dynamics with large oscillations around the MPP is obtained using a large step size, a slow tracking speed and less oscillations around the MPP is obtained using a small step size. Hence, the tradeoff between the dynamics and steady state accuracy must be established by the corresponding design. To overcome this problem, variable step-size MPPT methods have been proposed (Loukriz *et al*., 2016; Harrag and Messalti, 2015; Tey and Mekhilef, 2014; Safari and Mekhilef, 2011; Al-Diab and Sourkounis, 2010).

In this research, a new variable step-size IC MPPT controller for PV systems has been proposed to improve the tracking accuracy and dynamic performance providing the corresponding duty cycle under different atmospheric conditions. The proposed method was developed and tested successfully using a boost converter connected to a Sun Module (SW) 240 W. Simulations are provided in several aspects using MATLAB/Simulink Model for different atmospheric conditions. A comparative study between the proposed variable step size and fixed step size IC MPPT method under similar operating conditions is presented. Results and analysis are presented, in which many contribution have been demonstrated in terms of response time, MPPT tracking, reducing of oscillations.

MATERIALS AND METHODS

Modeling of PV cell: The PV generator consists of solar cells connected in series and parallel fashion to provide the desired voltage and current. The basic element of a PV system is the solar cell, a typical solar cell consists of a PN junction formed in a semi-conductor material similar to a diode, it can be represented as a current source model as shown in Fig. 1 (Loukriz *et al*., 2016; Rekioua and Matagne, 2012).

The solar cell terminal current can be expressed as a function of photo-generated current, diode current and shunt current as given by:

$$I_o = I_{ph} - I_d - I_{sh} \tag{1}$$

Where:

I_{ph} = The current generated by the incident light (it is directly proportional to the sun irradiation)
I_d = The current through the diode
I_{sh} = The current through the parallel resistor R_{sh}

The relationship between voltage and current of a PV array is given by Eq. 2:

$$I_0 = N_p I_{ph} - N_p I_{rs}\left[e^{\frac{q(V+R_s I_o)}{AkTN_s}} - 1\right] - N_p \frac{q(V+R_s I_o)}{N_s R_{sh}} \tag{2}$$

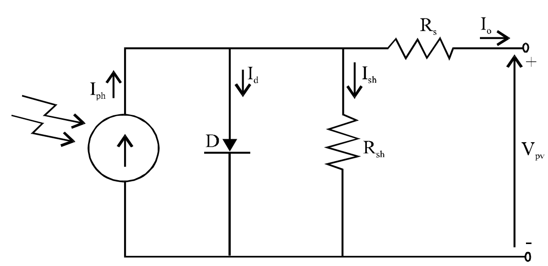

Fig. 1: Simplified equivalent circuit of a photovoltaic cell

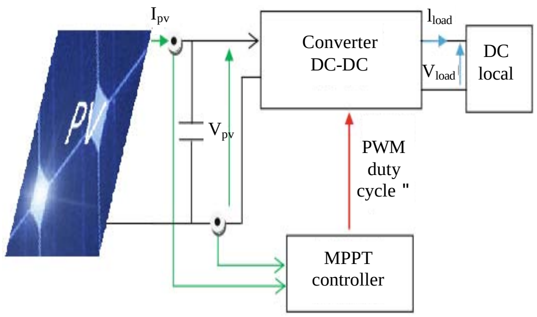

Fig. 2: PV system with MPPT controller

Where:

I_{rs} = The cell reverse saturation current
V = The cell output Voltage (V)
A = The diode ideality constant
T = The reference cell operating temperature
q = The electron charge (1.60217646×10^{-19} C)
k = The Boltzmann constant (1.3806503×10^{-23} J/K)
R_s and R_p = The series and shunt resistors of the cell, respectively

The generated photocurrent I_{ph} is related to the solar irradiation by Eq. 3:

$$I_{ph}=\frac{G}{1000}\left(I_{sc}+k_i\left(T\text{-}T_r\right)\right) \tag{3}$$

Where:

I_{sc} = The cell short circuit current at reference temperature and irradiation
G = The solar irradiation (W/m^2)
T_r = The cell reference temperature
k_i = The short-circuit current temperature coefficient

MPPT controller: The produced power from a given PV array depends mainly on weather conditions (solar irradiance and temperature). As these quantities vary with time, maximum power point tracking control algorithm is necessary to control and adjust continuously the voltage and current to the corresponding MPP value at any given time and under rapidly varying environmental conditions (insolation, shading, temperature, load), there is a unique operating point on the array's Power Voltage (PV) curve called the Maximum Power Point (MPP) where the power generation is maximum. The PV system with MPPT is shown in Fig. 2.

Conventional fixed step IC MPPT controller: The incremental conductance is widely used MPPT methods for its simplicity and ease of implementation, high tracking speed and better efficiency (Rekioua and Matagne, 2012; Harrag and Messalti, 2015; Li and Wang, 2009; Safari and Mekhilef, 2011). This method focuses directly on power variations. The output current and voltage of the photovoltaic panel are used to calculate the conductance and the incremental conductance. The basic equation of this method are as:

$$\frac{dP}{dV}=0 \tag{4}$$

Equation 4 can be rewritten as:

$$\frac{dP}{dV}=\frac{d(IV)}{dV}=I+V\frac{d(I)}{dV}=0 \tag{5}$$

$$\frac{dI}{dV}=-\frac{I}{V}\text{at MPP} \tag{6}$$

$$\frac{dI}{dV}>-\frac{I}{V}\text{ at left of MPP} \tag{7}$$

$$\frac{dI}{dV}<-\frac{I}{V}\text{ at right of MPP} \tag{8}$$

Proposed variable step IC MPPT controller: The performances of PV systems depends mainly on the step size. Therefore, a good calculation of step size provides a high performance of PV systems. The proposed variable step size IC MPPT algorithm is given as:

$$D(k)=D(k\text{-}1)\pm N*\left|\frac{dI}{D(k\text{-}1)}\right| \tag{9}$$

Where:

D(k) = The duty cycle
N = The scaling factor adjusted at the sampling period to regulate the step size which it's manually adjusted
dI = The PV array output current derivate

RESULTS AND DISCUSSION

To verify the efficiency and the performance of the proposed variable step size IC MPPT algorithm with direct control, a MATLAB/Simulink Model was designed based on boost converter connected to a Sun Module (SW) 240 W which their electrical parameters are listed in Table 1.

Figure 3 and 4 show the PV characteristics and 1-5 characteristics of the PV cell which are given from a typical PV panel Sun Module (SW) 240 W.

The proposed conventional incremental conductance fixed step size MPPT controller is tested and validated using MATLAB/Simulink Model under variable insolation levels G = 1000 and G = 800 W/m^2, results are shown in Fig. 5-7.

Table 1: Electrical characteristics of SUN Module (SW) 240 mono (1 kW/m^2, 25°C)

Descriptions	SW 240 mono
Maximum Power (Pm)	240 W
Voltage at Pmax (Vm)	30.6 V
Current at Pmax (Im)	7.87 A
Short circuit current (Isc)	8.22 A
Open circuit voltage (Voc)	37.6

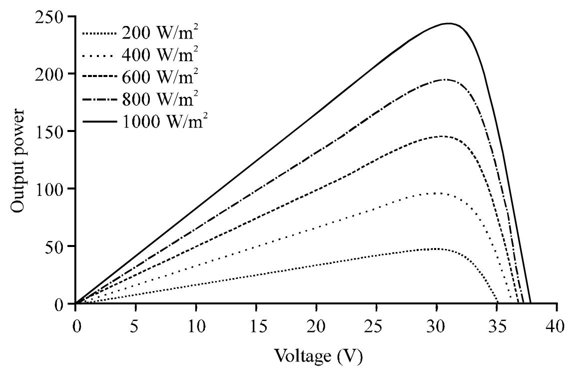

Fig. 3: P-V characteristics under various insolation levels

Figure 6 shows the output power performance of IC MPPT with fixed step size under insolation step-change conditions. The isolation was suddenly varied from 1000-800 W/m^2 at 0.5 sec. Figure 6 shows the PV characteristics of the PV system obtained by IC MPPT under two insolation levels: G = 1000 and G = 800 W/m^2.

To compare the performance of the fixed and proposed variable step size IC MPPT, many simulations have been carried out in same configuration and under exactly the same conditions. Figure 7-9 show the output

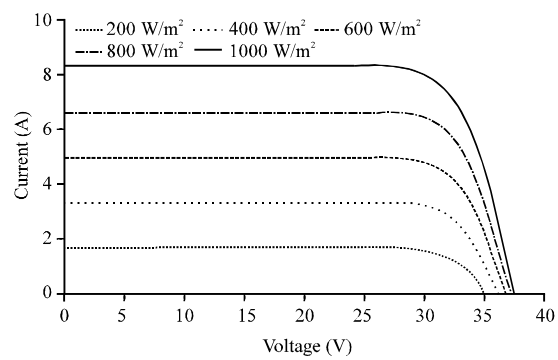

Fig. 4: I-V characteristics under various insolation levels

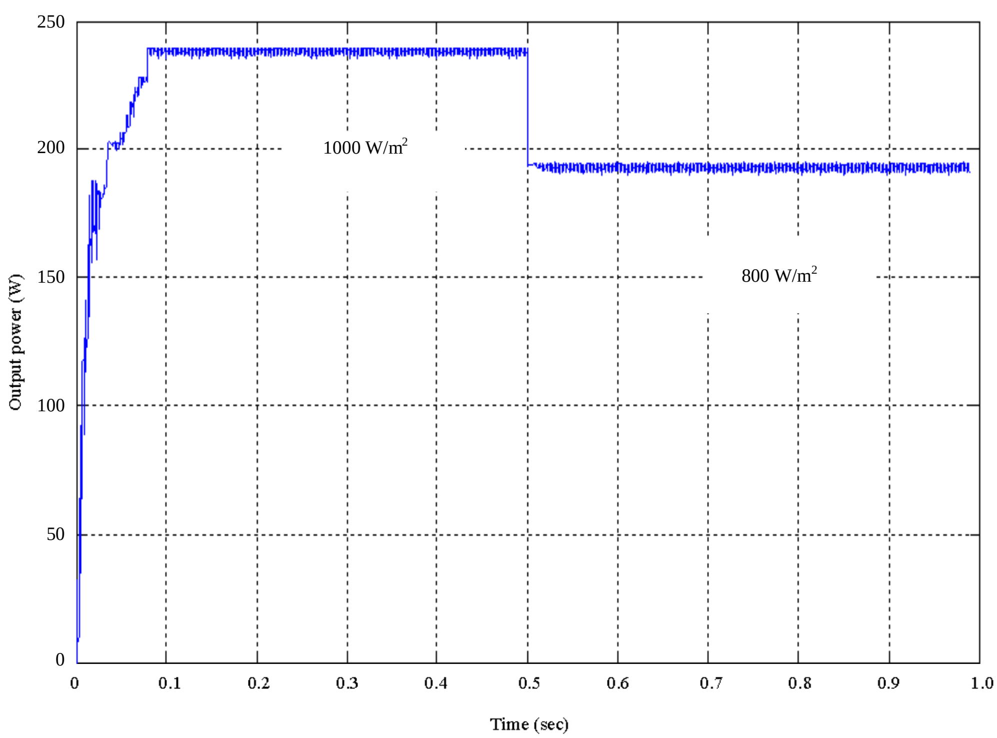

Fig. 5: PV array output power with IC fixed step size

performance of both fixed and variable step size IC MPPT methods. A comparative study between the fixed and proposed variable step size MPPT controllers was summarized in Table 2.

Table 2: Comparative results of the fixed and proposed variable step size IC MPPT

Performances	Fixed step size MPPT controller	Variable step size MPPT controller
MPPT tracking	Good	Good
Response time	Fast	Faster
Oscillation around MPP	High oscillation	Less oscillations
Accuracy	Good	Better

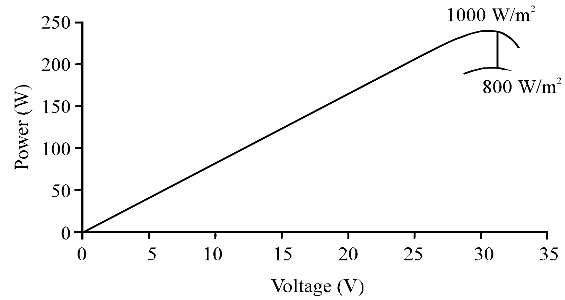

Fig. 6: PV characteristics under various insolation: G = 1000 and G = 800 W/m^2

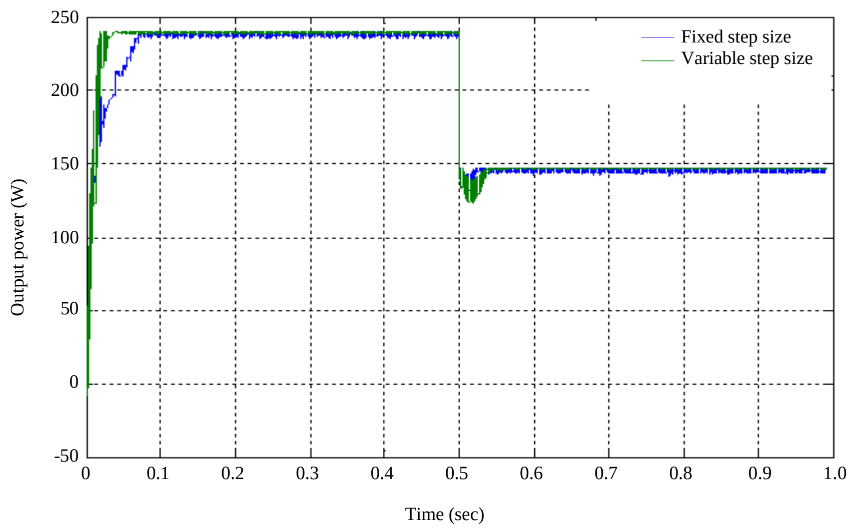

Fig. 7: PV array output power with fixed and variable step size MPPT controllers under various insolation G = 1000 and G = 800 W/m^2

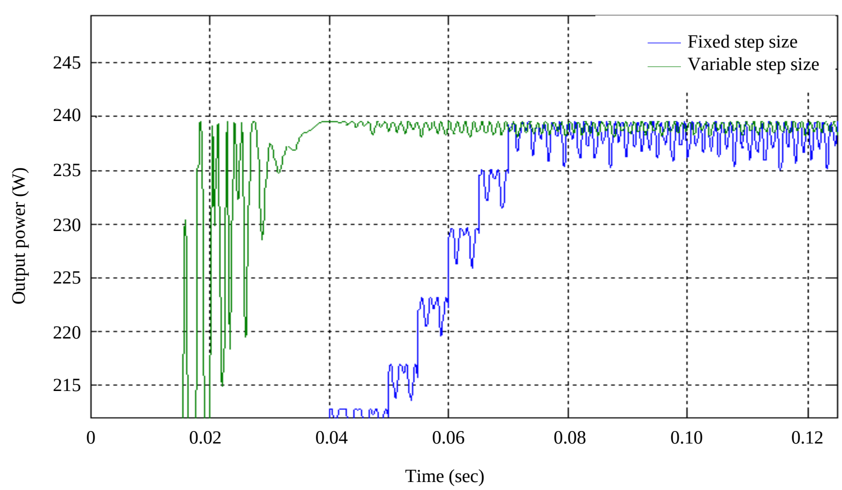

Fig. 8: PV array output power response time with fixed and variable step size MPPT controllers under various insolation G = 1000 and G = 800 W/m^2

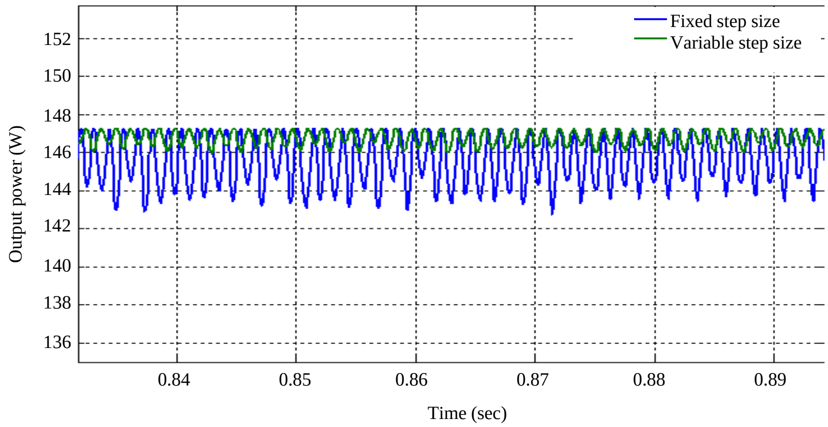

Fig. 9: PV array output power oscillation around MPP with fixed and variable step size MPPT controllers

CONCLUSION

In this study, a new variable step-size IC MPPT controller for PV systems has been proposed and investigated to improve the tracking accuracy and dynamic performance. The simulation results have been presented validating the performance and functionality of the proposed algorithm which a comparative study between the fixed and proposed variable step size IC MPPT controllers was established. The results demonstrate the high performances of the proposed variable step-size IC MPPT controller under fast changing insolation, from these results, the dynamic response is clearly faster than that with fixed step size MPPT. Thus, proposed variable step size IC MPPT controller can operate under variable insolation conditions. On the other hand, the oscillations around MPP point have been reduced using proposed MPPT controller, leading to fast convergence of the proposed variable step-size IC MPPT algorithm which results in better practical operating conditions than that with conventional IC MPPT method.

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