VOL. 8, NO. 7, JULY 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

A NEW APPROACH OF MODELLING, SIMULATION OF MPPT FOR PHOTOVOLTAIC SYSTEM IN SIMULINK MODEL

M. Abdulkadir, A. S. Samosir, A. H. M. Yatim and S. T. Yusuf
Department of Energy Conversion, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai, Johor Bahru, Malaysia
E-Mail: amusa2@live.utm.my

ABSTRACT

This paper presents the design and simulation for maximum power point tracking (MPPT) for photovoltaic system, which includes a high-efficiency dc-dc boost converter with a modified incremental conductance algorithm. The converter can draw maximum power from the PV panel for a given solar insolation and temperature by adjusting the duty cycle of the converter. The modelling procedure for the circuit model was presented using MATLAB/Simulink Sim-power. The MPPT system has been tested with solar panel ICO-SPC 100 W module under various operating conditions. The obtained results prove that the proposed MPPT can track even under sudden change in sunlight conditions and loading level.

Keywords: dc-dc boost's converter, maximum power point (MPP), maximum power point tracking (MPPT), photovoltaic (PV).

INTRODUCTION

Due to the world energy crisis and coupled with growing demand for energy has resulted in conventional energy sources unable to cope with the expected world energy demand soon. Therefore, developments in renewable and alternative energy systems are expected to increase. Thus, it is important to explore more and better means of alternative energy sources like solar, wind and biomass. Photovoltaic energy is a source of interesting energy; it is renewable, inexhaustible and non-polluting, and it is more and more intensively used as energy sources in various applications. In regard to endless importance of solar energy, it is worth saying that solar energy is a unique perspective solution for energy crisis. Meanwhile, despite all these advantages of solar energy, they do not present desirable efficiency (Abdulkadir, *et al*., 2012), (Adbullah, *et al*., 2012).

The efficiency of solar cells depends on many factors such as temperature, insolation, and spectral characteristics of sunlight; dust, shading, which result in poor performance. In addressing the poor efficiency of photovoltaic systems, various methods were proposed among which a concept is called “maximum point power tracking” (MPPT) is implored. The photovoltaic has an optimum operating point to extract the maximum power called the maximum power point (MPP), which varies depending on cell temperature, insolation level, the nature of load, the technology of the photovoltaic cells (Safari, 2011), (Zegaoui *et al*., 2011). The variation in solar irradiation and temperature causes the tracker to deviate from the maximum power point, thus the tracker needs to response within a short time to these variations to avoid energy loss. A variety of maximum power point tracking (MPPT) method is developed. The methods vary in implementation complexity, sensed parameters, convergence speed and cost, range of operation, popularity and their application (. Zegaoui *et al*., 2011; Kakosimos, 2011; Samosir, 2010; Lin *et al*., 2011; Moacyr *et al*., 2011; Zhang, *et al*., 2011).

Presently, the most commonly used algorithm is the perturbation and observation method (P and O), the incremental conductance method (INC) and Hill climbing. P and O method easily leads to erroneous judgment and oscillation around the maximum power point; it generally needs to combine one or several improvements for normal use. INC methods overcome these shortcomings of P and O methods but require relatively harsh detection devices and the choice of the step and threshold is also more stressful (Liu, *et al*., 2008).

For implementing the MPPT, there is a need to include the dc-dc converter into the system. The dc-dc converter can be either buck or boost converter. The buck converters are step-down switching-mode, and the boost converters are step-up power converters. They are popular because of their high efficiency and compact size (Walker, 2001). In this paper, the boost converter is chosen where the duty cycle of the boost dc-dc converter is controlled by PWM signal from controller implementing Incremental Conductance and integral regulator algorithm. Therefore, whatever the weather (irradiation and temperature) and the load conditions, the control system of the converter will ensure the operating point is optimized for maximum power transfer.

The Simulink model of the PV system under different temperature and irradiation is simulated and tested. The operating point of the PV on the I-V curve is dynamically modified by the controller so that the MPPT obtained the maximum power point at any sunlight conditions and maintain PV power in the neighbourhoods of this point to produce power with the higher efficiency. The whole system is as shown in Figure-1.

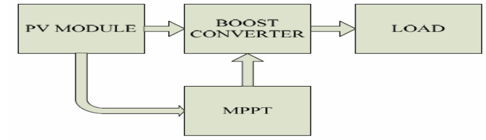


Figure-1. Block diagram of the proposed scheme.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MODEL VALIDATIONS OF THE PV SYSTEM

Photovoltaic cell models have long been a source for the description of photovoltaic cell behaviours for researchers and professionals. The most common model used to predict energy production in photovoltaic cell modeling is the single diode circuit model (Kashif *et al.*, 2011), (Pandiarajan *et al.*, 2011; Aissa Chouder *et al.*, 2011). The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source (I_{SC}) as shown in Figure-2.

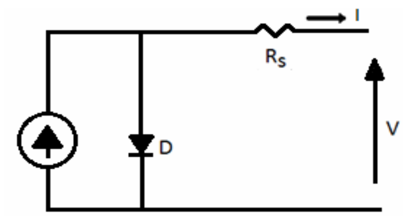


Figure-2. Solar cell model using single diode.

The equation for the output current is given by:

$$I = I_{SC} - I_D \quad (1)$$

Where

$$I_D = I_{SCref}\left[\exp\left(\frac{qV_{oc}}{kAT}\right) - 1\right] \quad (2)$$

The light current depends on both irradiance and temperature. It is measured at some reference conditions.

$$I_{SC} = [I_{SCref} + K_i(T_k - T_{ref})] * \sigma/1000 \quad (3)$$

Where

I = Solar cell current (A)
I_D = Module diode saturation current
I_{SCref} = Module short-circuit current at 25°C
q = Electron charge
V_{oc} = Module open circuit voltage
σ = The irradiation on the device surface (W/m2)
A = Ideality factor
T = Module operating temperature in Kelvin
I_{SC} = The photocurrent in (A)
T_k = The actual temperature in Kelvin (K)
T_{ref} = Reference temperature in Kelvin (K),
k = Boltzmann constant.

Equation (2) does not adequately represent the behaviour of the cell when subjected to environmental variations, especially at low voltage (Abdulkadir, *et al.*, 2012; Zegaoui *et al.*, 2011; Pandiarajan *et al.*, 2011). A more practical model is shown in Figure-3, where R_S and R_P represents the equivalent series and parallel resistance, respectively.

In this model, a current source I_{SC} which depends on solar radiation and cell temperature; a diode in which the inverse saturation current I_D depends mainly on the operating temperature; a series resistance R_S and a shunt resistance R_P which takes into account the resistive losses was considered.

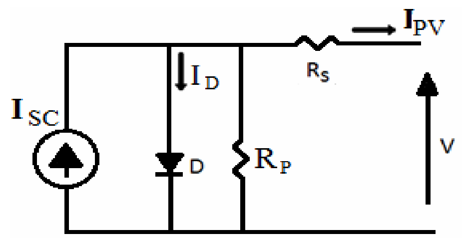


Figure-3. Solar cell model using single diode with R_s and R_p.

The equations that describe the, I-V and P-V characteristics of the circuit in Figure-3 are given by;

$$I_{SC} - I_D - \frac{V_D}{R_P} - I_{PV} = 0 \quad (4)$$

Thus,

$$I_{PV} = I_{SC} - I_D - \frac{V_D}{R_P} \quad (5)$$

And the reverse saturation current I_{rs} is given as

$$I_{rs} = I_{SCref}\left[\exp\left(\frac{qV_{oc}}{N_s kAT}\right) - 1\right] \quad (6)$$

The module saturation current I_D varies with the cell temperature which is given by;

$$I_D = I_{rs}\left[\left(T/T_{ref}\right)^3 e^{qC_g/Ak} * \left(1/T_{ref} - 1/T\right)\right] \quad (7)$$

Where I_D is the diode saturation current (A). The basic equation that describes the current output of the photovoltaic (PV) module I_{PV} of the single-diode model is as given in equation (8).

$$I_{PV} = N_P I_{SC} - N_S I_D\left\{\exp\left(\frac{q(V_{PV} + I_{PV}R_S)}{N_S AkT}\right) - 1\right\} - V_{PV} + \left(\frac{I_{PV}R_S}{R_P}\right) \quad (8)$$

Where k is the Boltzmann constant (1.38 x 10^{-23} J K^{-1}), q is the electronic charge (1.602 x 10^{-19} C), T is the cell temperature (K). A is the diode ideality factor, R_S the series resistance (Ω) and R_P is the shunt resistance (Ω). N_S is the number of cells connected in series, N_P is the

ARPN Journal of Engineering and Applied Sciences

number of cells connected in parallel, $V_{PV} = V_{OC} = 21.06V$ (Pandiarajan *et al*., 2011).

The nonlinear and implicit equation given by Eq. (4) depends on the incident solar irradiance, the cell temperature, and on their reference values (Abdulkadir, *et al*., 2012; Adbullah, *et al*., 2012).

These reference values are generally provided by manufacturers of PV modules for specified operating condition such as STC (Standard Test Conditions) for which the irradiance is $1000W/m^2$ and the cell temperature is 25^o C. Real operating conditions are always different from the standard conditions, and mismatch effects can also affect the real values of these mean parameters (Aissa Chouder *et al*., 2011; da Silva *et al*., 2010; Dell Aquila *et al*., 2010).

The use of the simplified circuit model in this work makes it suitable for power electronics designers to have an easy and effective model for the simulation of photovoltaic devices with power converters. Based on the above equations and using the electrical specifications presented in Table-1, the PV system model has been developed using MATLAB/Simulink as shown in Figure-4.

Table-1. Parameter specification of ICO-SPC 100 W PV module.

Maximum power	P_m	100W
Maximum voltage	V_m	17.3V
Current at max power	I_m	5.79A
Open circuit voltage	V_{oc}	20.76V
Short circuit current	I_{sc}	6.87 A
Total No. of cells in series	N_s	36
Total No. of cells in parallel	N_p	1

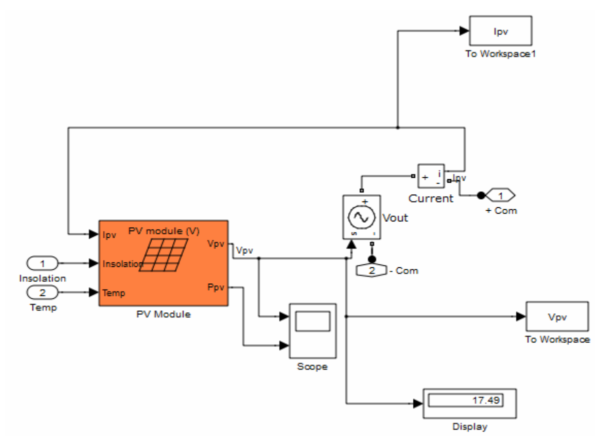


Figure-4. Simulink model of the PV system.

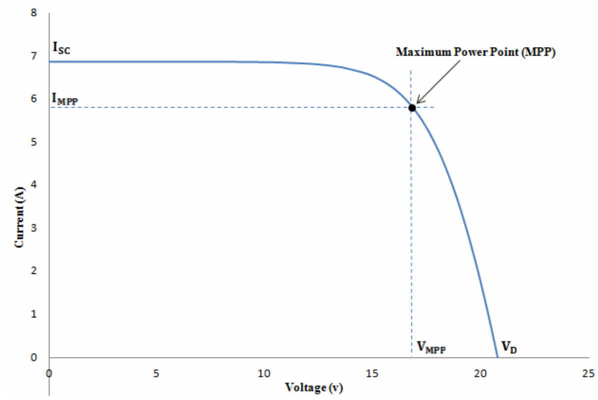


Figure-5. I-V Characteristic-constant irradiance.

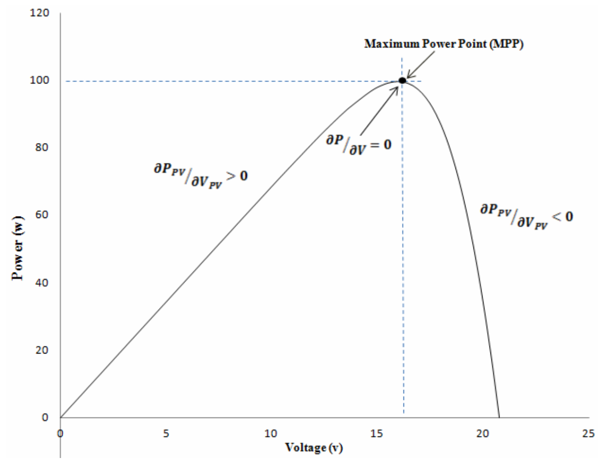


Figure-6. P-V characteristic-constant irradiance.

MPPT IN PHOTOVOLTAIC SYSTEMS

Photovoltaic (PV) modules are semiconductor's devices that are able to directly convert the incident solar radiation into electrical energy. On the I-V curve, there is a point called MPP (maximum power point) which always occurs in the knee of the curve, where the generated PV power is maximized as shown in Figure-5. Most of the maximum power point tracking (MPPT) algorithms searches the maximum power point (MPP) by comparing the output power of the PV module before, and after the duty cycle of the converter is changed (Issam Houssamo *et al*., 2010).

In this paper, the maximum power point tracking is achieved by Incremental Conductance method with the inclusion of an integral regulator. The theory of the incremental conductance method is to determine the variation in direction of the terminal voltage for PV modules by measuring and comparing the incremental conductance and instantaneous conductance of PV modules (Houssamo, *et al*., 2010; Luo *et al*., 2009; Wu, *et al*., 2009; Peftitsis, *et al*., 2008.

If the value of incremental conductance is equal to that of instantaneous conductance, the power delivered will be at its maximum point. This point can be obtained from the voltage and/or current measurements, and the

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MPPT algorithm calculates the optimal duty cycle D in order to maximize the power flow. Since the irradiance and temperature are dynamic in nature, the MPPT algorithm must work practically in real time, updating the duty cycle D constantly and maintaining the accuracy and speed of tracking.

PROPOSED MPPT METHOD

In order to operate a photovoltaic (PV) system within its MPP, and considering the irradiance and temperature variation, a maximum power point tracking algorithm is needed to search and maintain the peak power (Walker, 2001). The Incremental Conductance comes from the fact that it uses the derivative of the PV system conductance, in order to determine the operating point position in relation to MPP. In this work, the algorithm was modified in order to include an integral regulator. The integral regulator minimizes the error $(\frac{\partial I}{\partial V} + \frac{I}{V})$ where the regulator output will be equal to duty cycle correction. The power output from the solar PV modules is:

$$P = VI \qquad (9)$$

Maximum power point is obtained when $\frac{\partial I}{\partial V} = 0$

$$\frac{\partial P_{PV}}{\partial V_{PV}} = \frac{\partial (V_{PV} * I_{PV})}{\partial V_{PV}} = V_{PV} * \frac{\partial I_{PV}}{\partial V_{PV}} + I_{PV} \qquad (10)$$

$$\frac{\partial P_{PV}}{\partial V_{PV}} > 0 \; if \; \frac{I_{PV}}{V_{PV}} > -\frac{\partial I_{PV}}{\partial V_{PV}}, \text{ on the left of MPP;} \qquad (11)$$

$$\frac{\partial P_{PV}}{\partial V_{PV}} = 0 \text{ if } \frac{I_{PV}}{V_{PV}} = -\frac{\partial I_{PV}}{\partial V_{PV}}, \quad \text{at the MPP;} \qquad (12)$$

$$\frac{\partial P_{PV}}{\partial V_{PV}} < 0 \text{ if } \frac{I_{PV}}{V_{PV}} < -\frac{\partial I_{PV}}{\partial V_{PV}}, \text{ on the right of MPP;} \qquad (13)$$

$$< -\frac{\partial (V_{PV} * I_{PV})}{\partial V_{PV}} = I_{PV} + V_{PV} * \frac{I_{PV}}{V_{PV}} = 0 \qquad (14)$$

$$\frac{\partial I_{PV}}{\partial V_{PV}} = -\frac{I_{PV}}{V_{PV}} \qquad (15)$$

The present value and the previous value of the solar module voltage and current are used to calculate the values of ∂I_{PV} and ∂V_{PV}. If $\partial V_{PV} = 0$ and $\partial I_{PV} = 0$, then the atmospheric conditions have not changed and the MPPT is still operating at the MPP. If $\partial V_{PV} = 0$ and $\partial I_{PV} > 0$, the amount of radiation has increased, raising the MPP voltage [17]. This requires the MPPT to increase the PV module operating voltage to track the MPP. Otherwise, if $\partial I_{PV} < 0$, the amount of radiation has decreased, lowering the MPP voltage and requires the MPPT to decrease the PV module operating voltage. If $\frac{\partial I_{PV}}{\partial V_{PV}} = -\frac{I_{PV}}{V_{PV}}$, then $\frac{\partial P_{PV}}{\partial V_{PV}} > 0$, and the PV module operating point is to the left of the MPP on the P-V curve.

Thus, the PV module voltage must be increased to reach the MPP. Similarly, if $\frac{\partial I_{PV}}{\partial V_{PV}} = -\frac{I_{PV}}{V_{PV}}$, then $\frac{\partial P_{PV}}{\partial V_{PV}} < 0$ and the PV module operating point lies to the right of the MPP on the P-V curve, showing that the voltage must be reduced to reach the MPP. In this work, a small marginal error could be added to the maximum power conditions such that the MPP is assumed to occur if

$$\left[\frac{\partial I_{PV}}{\partial V_{PV}} + \frac{I_{PV}}{V_{PV}}\right] < \varepsilon \qquad (16)$$

The value of ε was determined with consideration of the trade-off between the problem of not operating exactly at the MPP and the possibility of oscillating around it. This also depends on the chosen perturbation step size.

The implementation of this method can be done adding a controller to improve the incremental conductance method minimizing the error between the actual conductance and the incremental conductance, because the compensator can be adjusted and updated according to the system necessity. Besides, this controller can reduce the ripple oscillations in steady-state minimizing the issues involving digital resolution implementation. This method can be seen as an adaptative solution once it presents large step sizes when the PV operating point is far from the MPP, then the step sizes are reduced according to the distance of MPP and finally when the MPP is achieved the system operation point is not changed, unless the climate conditions are also changed. The controller can control the duty cycle (d) of the converter directly to find the MPP. Figures 8 (a) and (b) show the Matlab/Simulink of the modified Incremental Conductance with integral regulator.

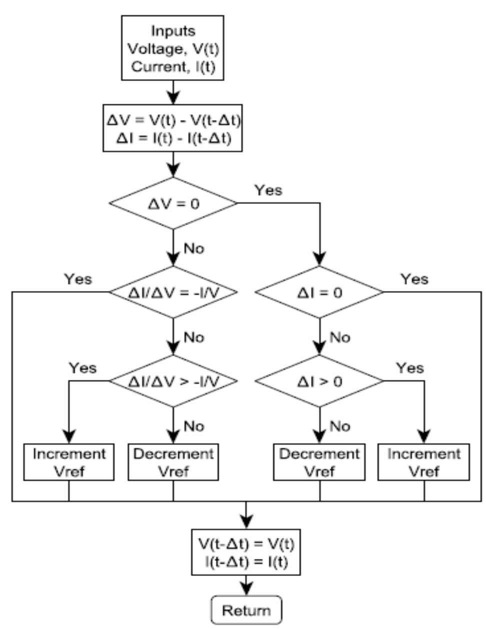
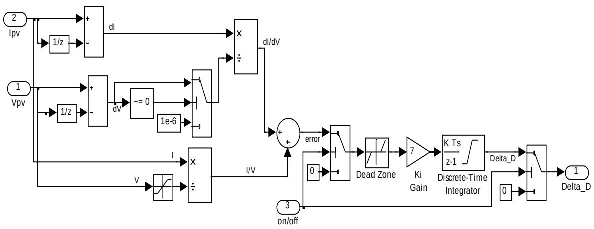
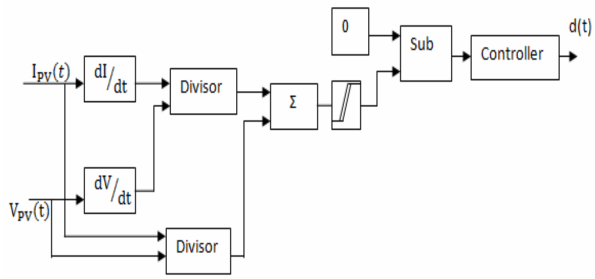


Figure-7. Flow chart of the INC algorithm.

VOL. 8, NO. 7, JULY 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



(a)



(b)

Figure-8. Modified Increment Conductance with integral regulator Matlab/Simulink.

SIMULATION RESULTS AND ANALYSIS

Based on the modified algorithm, the simulation was conducted using dc-dc boost converter system implemented with SimPower Systems toolbox of MATLAB/Simulink model. The simulation system consists of photovoltaic module, dc/dc boost converter circuit, resistive load and control module as shown in Figure-9. An algorithm based on Incremental Conductance, and integral regulator method has been developed for real time tracking. This method uses the slope of the derivative of the current with respect to the voltage in order to reach MPP. From the voltage V and the current I measurements, the algorithm calculates the photovoltaic output power and its derivative as a function of the voltage.

The simplified flow chart of this method is given in Figure-7. Figure-10 to Figure-12 presents the PV output voltage, current, power across the dc/dc converter with MPPT and without MPPT. An MPPT enable was incorporated into the algorithm set at initialized time and in this paper, the enabled time was set to 0.02ms. After the transient response, it is noted that the PV voltage V is established exactly on the MPP voltage and in consequence, the power flow is optimized. Two different load conditions R1 and R2 were incorporated with a switch to test the variation in load at different time.

From the graph, this proved that the MPPT algorithm was able to track the MPP. Thus with this simulation tool, it has highlighted the fact that the advantages of the incremental conductance to other algorithms by a faster achievement of the MPP which is carried out immediately in the good direction without additional oscillations when the MPP is reached in case of sudden change in load.

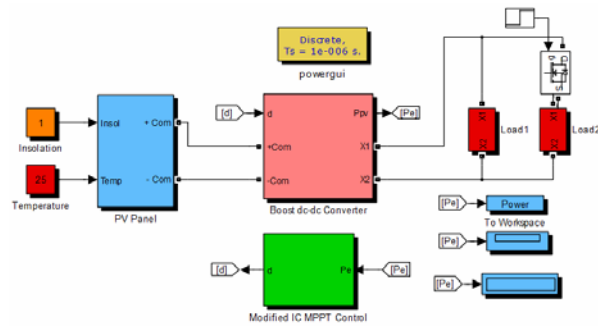
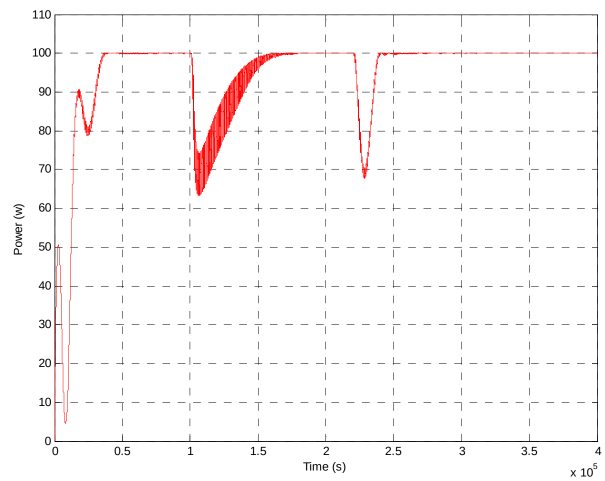
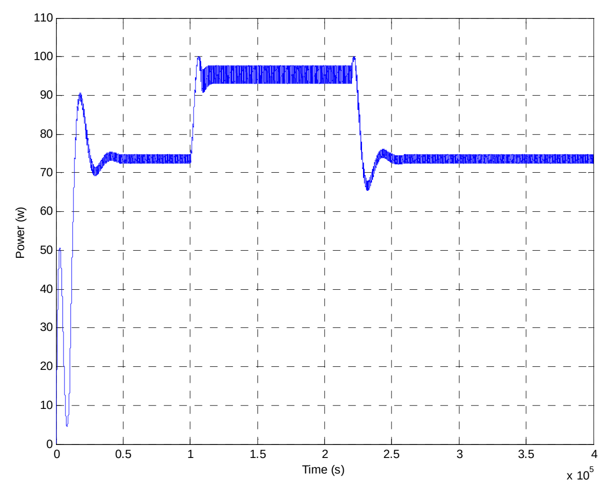


Figure-9. MPPT Control PV MATLAB/Simulink model.



(a)

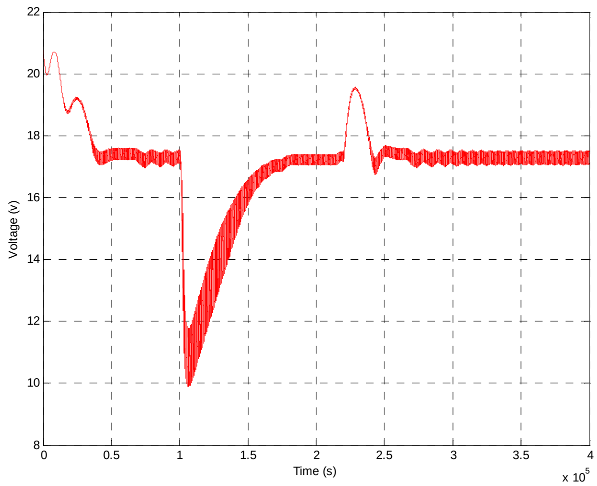


(b)

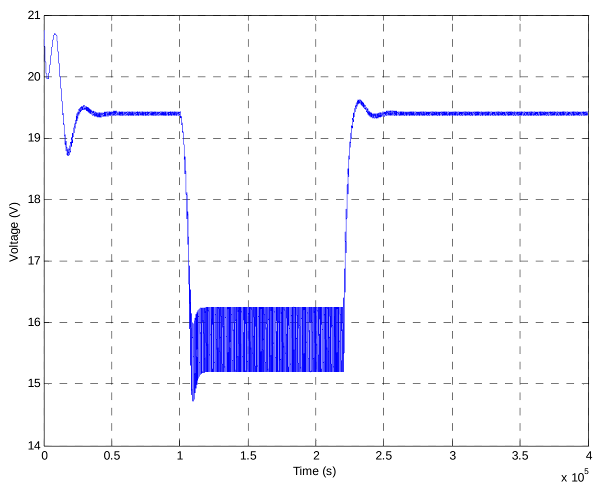
Figure-10. Output power of the PV (a) with and (b) Without MPPT under varying load conditions.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

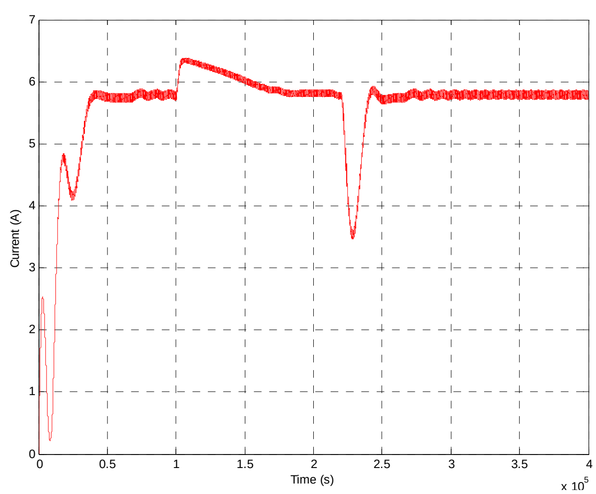


(a)

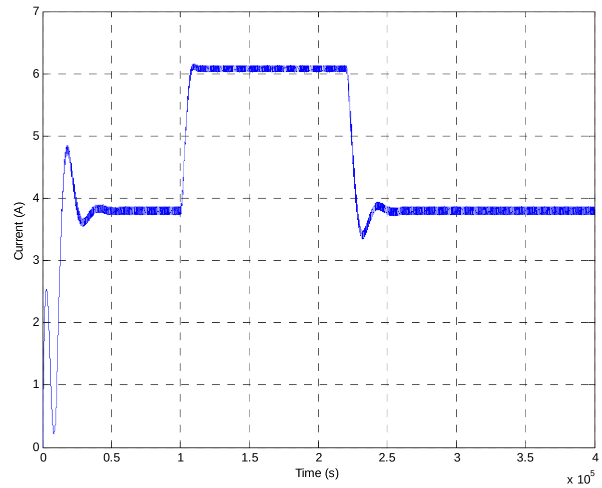


(b)

Figure-11. Output voltage of the PV (a) with and (b) Without MPPT under varying load conditions.



(a)



(b)

Figure-12. Output current of the PV (a) with and (b) Without MPPT under varying load conditions.

CONCLUSIONS

This paper has presented all procedure to the development of maximum power point algorithm based on modified incremental conductance. The modelling and simulation of the maximum power point tracking algorithm was implemented in Matlab/simulink environment. The role of the maximum power point tracking, was to match the load power required with a maximum of the available power that can be generated from a photovoltaic module. The simulation result prove that the modified incremental conductance MPPT reaches the intended maximum power point. Beside the tracking elapsed time of the incremental conductance method, it has advantage of exact perturbing and tracking direction and steady perturbing period.

REFERENCES

Abdulkadir M, *et al*. 2012. Modeling and Simulation based Approach of Photovoltaic system in Simulink model. ARPN Journal of Engineering and Applied Sciences. 7(5): 616-623.

Adbullah M.A, *et al*. 2012. A review of maximum power point tracking algorithms for wind energy systems. Renewable and Sustainable Energy Reviews. 16: 3220-3227, June.

Aissa Chouder *et al*. 2011. Modeling and simulation of a grid connected PV systems based on the evaluation of main PV module parameters, Sciverse Science Direct.

da Silva R. M. and J. L. M. Fernandes. 2010. Hybrid photovoltaic/thermal (PV/T) solar systems simulation with Simulink/Matlab. Solar Energy. 84: 1985-1996.

Dell Aquila R. V. 2010. A new approach: Modeling, simulation, development and implementation of a commercial grid-connected transformer less PV inverter. pp. 1422-1429.

Houssamo, et al. 2010. Maximum power tracking for photovoltaic power system: Development and experimental comparison of two algorithms. Renewable Energy. 35: 2381-2387.

Issam Houssamo, *et al*. 2010. Maximum power tracking for photovoltaic power system: development and experimental comparison of two algorithms, Renewable Energy. pp. 2381-2387.

Kakosimos P. E. and A. G. Kladas. 2011. Implementation of photovoltaic array MPPT through fixed step predictive control technique. Renewable Energy. 36: 2508-2514, September.

Kashif Ishaque, Zainal Salam and Hamed Tahri. 2011. Accurate MATLAB/Simulink PV systems simulator based on a two-diode model. Journal of power electronics. 11(2).

Lin C.-H, *et al*. 2011. Maximum photovoltaic power tracking for the PV array using the fractional-order incremental conductance method. Applied Energy. 88: 4840-4847.

Liu F, *et al*. 2008. A variable step size INC MPPT method for PV systems. Ieee Transactions on Industrial Electronics. 55: 2622-2628, Jul.

Liu, *et al.* 2007. Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array.

Luo W. and G. Han. 2009. The Algorithms Research of Maximum Power Point Tracking in Grid-connected Photovoltaic Generation System.

Moacyr G, *et al*. Evaluation of MPPT techniques for photovoltaic applications. IEEE 2011. pp. 1039-1044.

Pandiarajan N. and Ranganath Muthu. Mathematical modeling of Photovoltaic module with Simulink, IEEE 2011. pp. 258-263.

Peftitsis D, *et al.* 2008. An investigation of new control method for MPPT in PV array using DC/DC buck- boost converter.

Safari and S. Mekhilef. 2011. Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter. IEEE Transactions on Industrial Electronics. 58: 1154-1161, April.

Samosir A.S and Yatim A. H. M. 2010. Dynamic evolution control for synchronous buck dc-dc converter, Theory, model and simulation, Elsevier. 18: 663-676.

Sinha K, *et al.* 2010. Design and Testing of PV Maximum Power Tracking System with MATLAB Simulation. In: Tencon 2010: 2010 Ieee Region 10 Conference. T. A. K. N. H. Okado, (Ed.). pp. 466-473.

Walker G. 2001. Evaluating MPPT converter topologies using a MATLAB PV model. Journal of Electrical and Electronics Engineering, Australia, IE Aust. 21(1): 49-56.

Wu Y.-E, *et al.* 2009. Research and Improvement of Maximum Power Point Tracking for Photovoltaic Systems.

Zegaoui *et al*. 2011. Comparison of two maximum power point trackers by simulating of PV generators, Science Direct. pp. 678-687.

Zhang L, *et al.* 2011. A New Approach to Achieve Maximum Power Point Tracking for PV System With a Variable Inductor. IEEE Transactions on Power Electronics. 26: 1031-1037, April.