2012 IEEE International Conference on Power and Energy (PECon), 2-5 December 2012, Kota Kinabalu Sabah, Malaysia

Modelling and Simulation of Maximum Power Point Tracking of Photovoltaic System in Simulink model

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***Abstract:*-Due to world energy crisis and growing demand for energy as the conventional energy sources have become increasingly unable to meet the world demand for the energy. This paper present the design and simulation for maximum power point tracking for photovoltaic system which include a high efficiency dc-dc boost converter with a modified incremental conductance algorithm. The converter is able to 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 100w module under various operating conditions. The obtained results have proven that the MPP is tracked even under sudden change in environmental conditions and loading level**

***Index Terms*:-dc-dc boost Converter, Maximum Power Point (MPP), Maximum Power Point Tracking (MPPT), Photovoltaic (PV).**

I. INTRODUCTION

With world economic development and growing demand for energy, the conventional energy sources have become increasingly unable to meet the world demand for the energy. Thus, it is important to explore more and better means of an alternative energy sources like sunlight, 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 prospective solution for energy crisis. Meanwhile, despite all these advantages of solar energy, they do not present desirable efficiency [1], [2].

The efficiency of solar cells depends on many factors such as temperature, insolation, 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 [3], [4]. 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) methods is developed. The methods vary in implementation complexity, sensed parameters, convergence speed and cost, range of operation, popularity, ability to detect multiple local maxima, and their application [5]-[8] and [26].

Presently, the most commonly used algorithm is the perturbation and observation method (P&O), the incremental conductance method (INC) and Hill climbing [9]. P&O method easily leads to erroneous judgement 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&O methods but require relatively harsh detection devices and the choice of the step and threshold is also more stressful [10].

For implementing the MPPT, there is 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 [11]. In this paper, the boost converter is chosen where the duty cycle of boost dc-dc converter is controlled by PWM signal from controller implementing Incremental Conductance and integral regulator algorithm. Therefore, whatever the weather conditions (irradiation and temperature) and whatever the load, the control system of the converter must place the system at the optimal power point (MPP). The Simulink model of the PV system under different temperature and irradiation was simulated and tested. The operating point of the PV on the I-V curve is dynamically modified by the controller so that the MPPT get the maximum power point at any moment and maintain PV power in the neighbourhoods of this point to produce power with the higher efficiency. The whole system is as shown in Fig 1 [17].

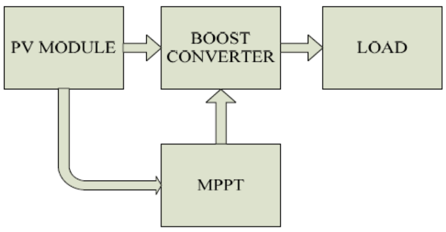


Fig 1 Block diagram of the proposed scheme

II. MODEL VALIDATIONS OF 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 modelling is the single diode circuit model [13], [14], [16], [18], [19]. The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source (I_{SC}) as shown in Fig 2.

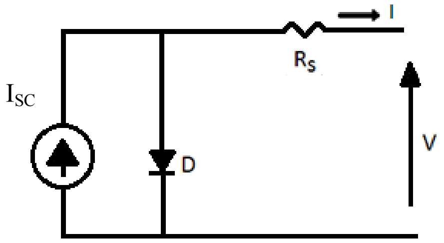


Fig. 2 Solar cell model using single diode

The equation for the output current is given by:

$$I = I_{SC} - I_D \tag{1}$$

Where

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

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

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

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 and T_{ref} = the actual and reference temperature in Kelvin (K),
k = Boltzmann constant [9].

Equation (2) does not adequately represent the behaviour of the cell when subjected to environmental variations, especially at low voltage [1], [4], and [11]. A more practical model is shown in Fig. 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.

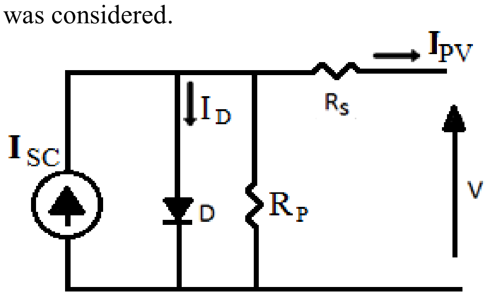


Fig. 3 Solar cell model using single diode with R_S and R_P

The equations that describe the I-V and P-V characteristic of the circuit in Fig. 3 is given by;

$$I_{SC} - I_D - \frac{V_D}{R_P} - I_{PV} = 0 \tag{4}$$

Thus,

$$I_{PV} = I_{SC} - I_D - \frac{V_D}{R_P} \tag{5}$$

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

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

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

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

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).

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

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 number of cells connected in parallel, $V_{PV} = V_{OC} = 21.06V$ [9]. The nonlinear and implicit equation given by Eq. (4) depends on the incident solar irradiance, the cell temperature, and on their reference values [1]-[4]. 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°C. Real operating conditions are always different from the standard conditions, and mismatch effects can also affect the real values of these mean parameters [16], [18].

The use of 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 Fig 4.

TABLE 1

Parameter specification of ICO-SPC 100w PV Module [9]

Parameter	Variable	Value
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
Total No. of cells in series	N_s	36
Total No. of cells in parallel	N_p	1

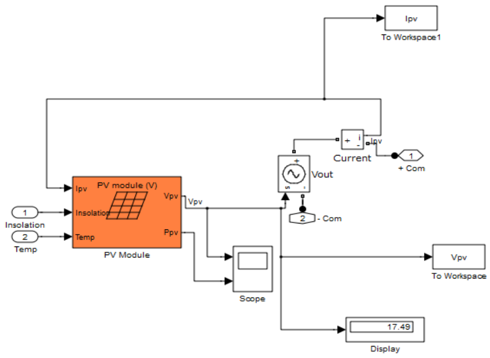


Fig 4 Simulink Model of the PV system

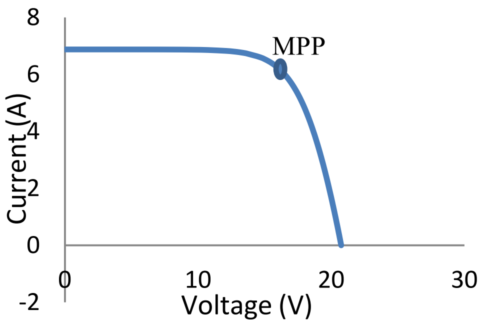


Fig 5 I-V Characteristic-Constant Irradiance

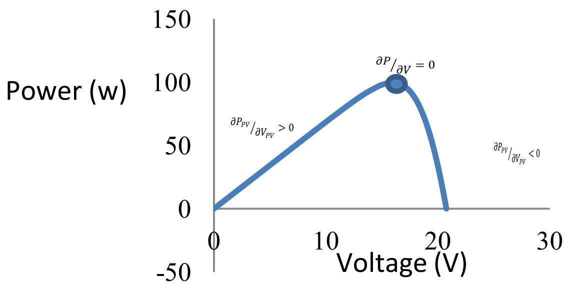


Fig 6 P-V Characteristic-Constant Irradiance

III. MPPT IN PHOTOVOLTAIC SYSTEMS

Photovoltaic (PV) modules are semiconductors 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 occur on the knee of the curve, where the generated PV power is maximized as shown in Fig 5. Most of the maximum power point tracking (MPPT) algorithms is a control algorithm which searches the maximum power point (MPP) comparing the output power of the PV module before and after the duty cycle of the converter is changed [22]. The commonly employed algorithms in PV maximum power point tracking systems are constant voltage, perturb and observe (P&O), seeking algorithm, sampling method, artificial intelligence method, open circuit voltage, short circuit current [20]-[25], and Incremental Conductance [5], [10] and [17]. In most of these algorithms, it is desired to optimise the power flow from the PV system to the load. When this is required, the operation point of the system must be maintained at the MPP. As the MPP depends on irradiation and temperature, these environmental conditions varies randomly, thus, the MPP position is constantly changed. In most applications, the dc-dc converter is connected between the PV module and the load, and its control is achieved through a tracking algorithm [11]. In this paper, the maximum power point tracking is achieved by Incremental Conductance plus 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 [10]-[17]. If the value of incremental conductance is equal to that of instantaneous conductance, it represents that the maximum power point is obtained or from the voltage and/or current measurements, the 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 keeping the accuracy and speed of tracking.

IV. PROPOSED MPPT METHOD

In order to operate a PV system within its MPP, whatever the irradiance and temperature variation, a maximum power point tracking algorithm is needed to find and maintain the peak power [23]. 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 [10], [17]. In this work, the algorithm was modified in order to include 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:

$$P = VI \tag{9}$$

Maximum power point is obtained when $\frac{\partial I}{\partial V} = 0$ [17]

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

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

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

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

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

$$\frac{\partial I_{PV}}{\partial V_{PV}} = -\frac{I_{PV}}{V_{PV}} \tag{15}$$

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. 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 $\frac{\partial \mathrm{I_{PV}}}{\partial \mathrm{V_{PV}}} = -\frac{I_{PV}}{V_{PV}}$, then $\frac{\partial \mathrm{P_{PV}}}{\partial \mathrm{V_{PV}}} > 0$, 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 $\frac{\partial \mathrm{I_{PV}}}{\partial \mathrm{V_{PV}}} = -\frac{I_{PV}}{V_{PV}}$, then $\frac{\partial \mathrm{P_{PV}}}{\partial \mathrm{V_{PV}}} < 0$ 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 be found if

$$\left[\frac{\partial \mathrm{I_{PV}}}{\partial \mathrm{V_{PV}}} + \frac{I_{PV}}{V_{PV}}\right] < \varepsilon \tag{16}$$

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. A contribution in the implementation of this method can be done adding a controller to improve the IC 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 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 modified. The digital controller can control direct the duty cycle (d) or the converter current (i_L). With this both constraints it is possible to find the MPP. Using i_L rather than d it makes the control more attractive once it permits that great changes in environmental conditions can be described as small changes in the converter current; however, if d is the control action great changes means big changes in the operation point of the converter. Thus, the controller bandwidth must be reduced in the second case. Fig 8 (a) and (b) show the MatLab/Simulink of the modified Incremental Conductance with integral regulator [28].

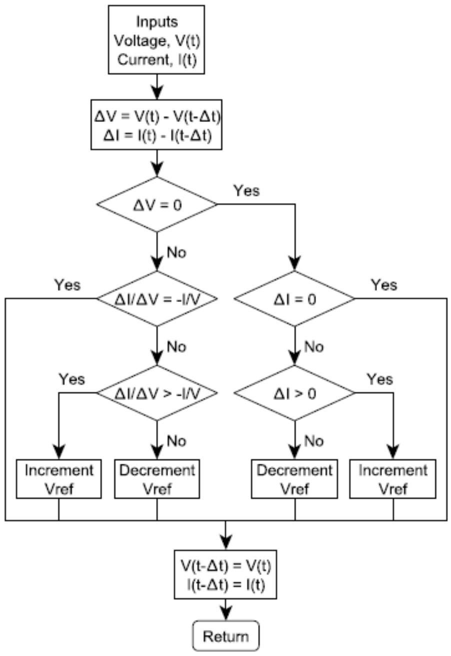
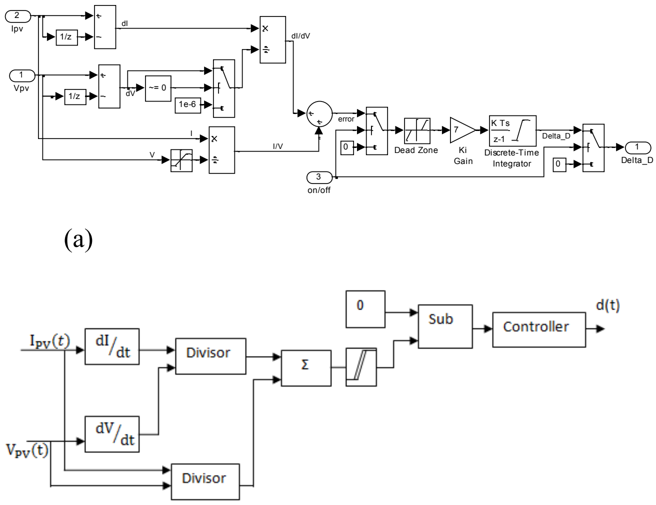


Fig 7 Flow chart of the INC algorithm



(a)

(b)

Fig 8 Modified Increment Conductance with integral regulator MatLab/Simulink

V. 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 Fig 9. An algorithm based on Incremental Conductance and integral regulator method has been developed for real time tracking. This method consists in using 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 out power and its derivative in function of the voltage $\frac{\partial \mathrm{P}}{\partial \mathrm{V}}$.

To obtain this point, $\frac{\partial P}{\partial V}$ must be equal to –I/V. The simplied flow chart of this method is given in Fig 7. Also, Fig 11 to Fig 13 presents the PV output voltage, current, power and the output voltage across the dc/dc converter with and without MPPT. An MPPT enable was incorporated into the algorithm set at initial time and in this case, the enable 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. A different load conditions R1 and R2 was incorporated with a switch to test the variation in load at different time. Under all conditions, it was able to track the maximum power point as can be seen in Fig 11. Also, with the same setup under the same condition, the simulation was test with no MPPT (MPPT disable) and we noticed that the PV voltage is stable in the system drove with this MPPT algorithm and, on the contrary, it is variable according to the load without MPPT as can be seen in Fig 13. The PV voltage at 19V for load R1 and later dropped to 15V at load R2 and then back to 19V for R1again, consequently the power dropped to 70W. This proved that the MPPT algorithm was able to track the MPP. As shown, with the Incremental Conductance MPPT, one tends directly toward this MPP; thus with this simulation tool, one have highlight the fact that the advantages of the incremental conductance to other algorithm 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.

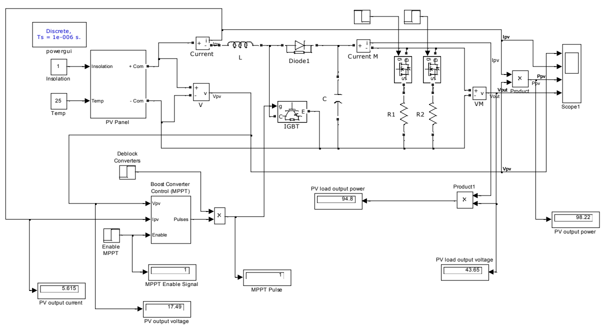


Fig 9 MPPT Control PV MATLAB/Simulink model

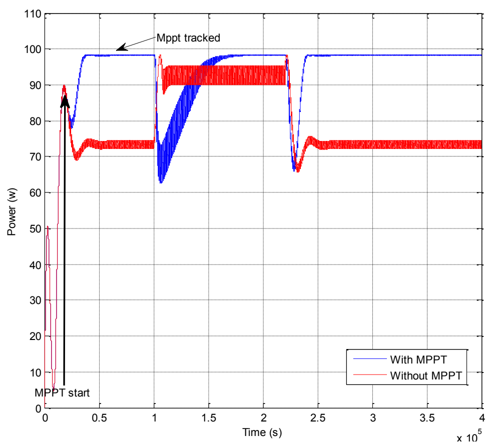


Fig. 10 Output Power of the PV with and Without MPPT under varying load conditions.

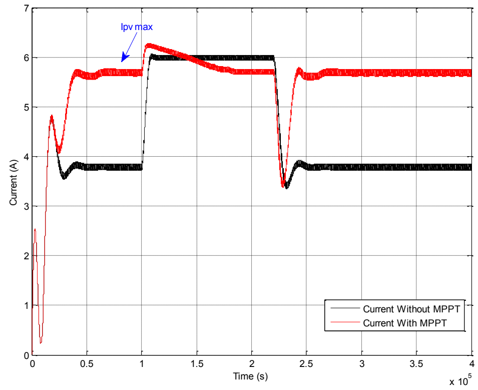


Fig. 11. Output Current of the PV with and Without MPPT under varying load conditions.

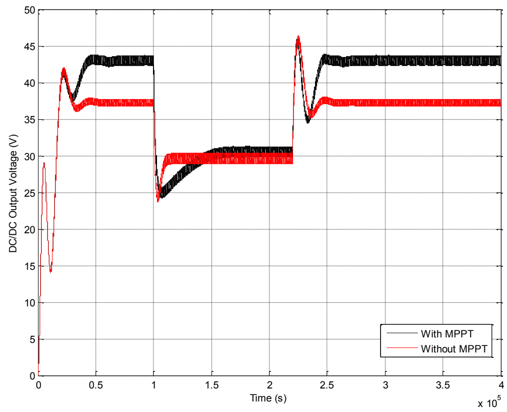


Fig. 12. Output voltage of dc/dc converter of the PV with and Without MPPT under varying load conditions.

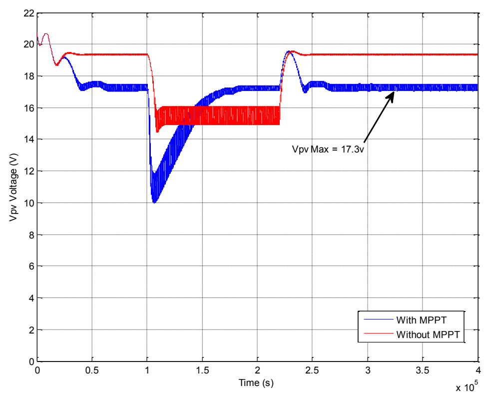


Fig. 13. Output voltage of the PV with and Without MPPT under varying load conditions.

VI. CONCLUSION

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.

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