Power Load Optimization for a Remote Area BTS Site Using MPPT Algorithms

Bahaa Abdulkhaliq Numan[1], Dr. Anas Lateef Mahmood[2]

[1]Electronic and communications engineering department, College of engineering, Al-Nahrain university, Baghdad, Iraq, bahaaabdulkhaliq@gmail.com.

[2]Electronic and communications engineering department, College of engineering, Al-Nahrain university, Baghdad, Iraq, anaslatif 78@yahoo.com.

Abstract: Solar energy is one of the most significant renewable energy sources. It has advantages of no pollution and does not make any noise and for this reasons the using of solar energy is increased rapidly in the last years. Solar energy depends on the environmental factors, such as temperature (T) and irradiation (G), which are dynamic, therefore it requires to obtaining the maximum power at any ambient conditions to support the load with the required power. Maximum power point tracking (MPPT) is one of the methods which widely used to optimize system performance and many MPPT techniques have been published such as hill climbing (HC) and incremental conductance (IncCond) methods**.** This paper deals with tracking the maximum power point (MPP) of standalone photovoltaic (PV) source used to support the rural area base transceiver station (BTS) that uses the MOTOROLA (Horizon II macro) equipment at changing the ambient conditions. The comparison of the two MPPT algorithm methods (HC and IncCond) to maximize the obtained solar power is achieved. Also an equation for calculating input capacitor value used in buck boost converter (BBC) design was developed in this paper. The KC65T solar module is used as the PV panel in this work. Simulation results are obtained using MATLAB program (Ver.14). The main result of the comparisons shows that the IncCond method is better than the HC method in fast environmental conditions changing.

Keywords: PV system; BBC; BTS; MPPT; HC algorithm; IncCond algorithm.

1. Introduction:

PV technology is elegant and benign, with a number of striking advantages over conventional methods of electricity generation. First and foremost, solar energy is the world's major renewable energy resource. PV power can be generated from the Sun anywhere. PV could in the long run make a major contribution to national energy security and carbon dioxide abatement [1]. PV systems can be grouped into grid connected systems and stand-alone systems. The first cost-effective applications for PV were stand-alone systems, these systems could be installed if it was impossible to install an electricity supply from the mains utility grid, or if this was not cost-effective or desirable [2].

The voltage produced by the photovoltaic cells will vary according to the sunlight intensity ,but the system output requires a constant voltage value to be able to process and control the electric energy in the system therefore there is a need for a power electronic interface [3].

The power generated from PV source mainly depends on the solar irradiance and ambient temperature (*T* in Kelvin). These quantities vary with time therefore various conventional (MPPT) algorithms have been proposed and used to extract PV source maximum power under different operating conditions [4]. The MPPT is an electrical circuit which can control the effective load resistance which the Photovoltaic Array (PVA) sees and thus control the point on the current-voltage characteristic at which the system operates [1]. In this paper two methods of how to track the MPP of a PV sources have been used to solve efficiency problem. These methods are HC method and IncCond method.

2. PV System Configuration

Figure 1 shows a block diagram of tracking system. A MPP tracker is used for obtaining the maximum power from the solar PV source. A non isolated DC-DC converter offers the purpose of conversion maximum power to the load. By varying the ratio of duty cycle, the impedance of load as it appears by the source is varied and matched at the peak power point with the source in order to obtain the maximum power.
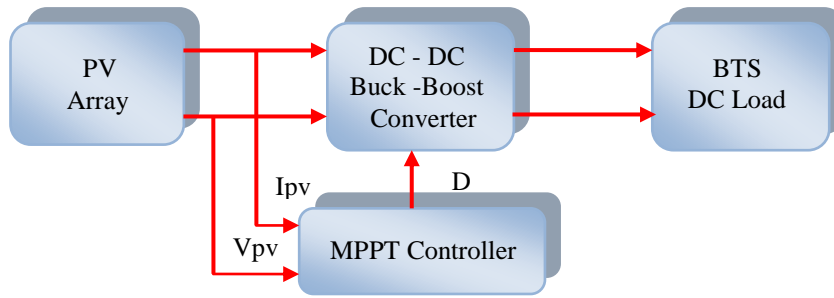
Figure 1: Block diagram of tracking system

2.1 Modelling of PV Array and Mathematical Equations:

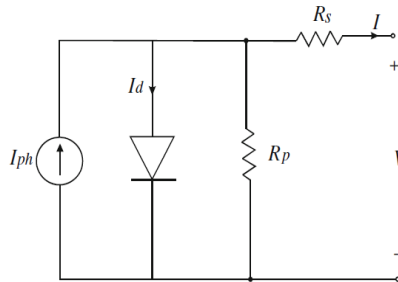An electrical circuit representing the solar cell is shown in figure 2 below [5].

Figure 2: Equivalent circuit of PV cell.

here, I_{ph} is the photo current generated by the cell, I_d is the diode current, , R_p is the parallel resistance, R_s is the series resistance, I is the output current of a solar cell and V is the output voltage of a solar cell.

A number of cells connected in series (N_s) consist a module. A PVA consists of number of solar modules connected in series and parallel ($N_{ss} * N_{pp}$) in order to obtain the desired voltage and current [6]. The output current of a PVA is defined as [7]

$$I = N_{pp} I_{ph} - N_{pp} I_{sat} \left[exp\left(\frac{V + IR_s \left(\frac{N_{ss}}{N_{pp}} \right)}{V_t \, a \, N_{ss}} \right) - 1 \right] - \frac{V + IR_s \left(\frac{N_{ss}}{N_{pp}} \right)}{R_p \left(\frac{N_{ss}}{N_{pp}} \right)} \tag{1}$$

where N_{pp} is the number of parallel module in PV array, I_{sat} is the diode saturation current, N_{ss} is the number of series module in PV array, a is the diode ideality factor, V_t is the thermal voltage with Ns cells connected in series.

The ideality factor value (*a*) depends on PV technology [8] so a=1.3 for Si-Polycrystal. Iterative method was used by [9] to calculated the values of R_s and R_p that makes the mathematical power-voltage (P-V) curve peak coincide with the experimental peak power at the (V_{mpp}, I_{mpp}) point by iteratively increasing the value of R_s while simultaneously calculating the value of R_p. The equation for (I_{ph}) as a function of temperature and irradiation level can be written as [9]

$$I_{ph} = \left(I_{ph,STC} + K_i \, \Delta_T \right) \frac{G}{G_{STC}} \tag{2}$$

where $I_{ph,STC}$ is

$$I_{ph,STC} = \frac{R_p + R_s}{R_p} \, I_{sc,STC} \tag{3}$$

An improved equation to describe the saturation current (I_{sat}) which considers temperature variations is given by [10]

$$I_{sat} = \frac{I_{sc,STC} + K_i \, \Delta_T}{exp\left[\frac{(V_{oc,STC} + K_v\Delta_T)}{aV_t}\right] - 1} \quad (4)$$

A KC65T Multicrystal PV module was used as reference model in this paper and its specifications are given in table 1.

Table 1: Electrical characteristic data of KC65T module.

Parameter	Value
Maximum power (Pmax)	65W (＋10%／−5%)
Maximum power voltage (Vmpp)	17.4V
Maximum power current (Impp)	3.75A
Open circuit voltage (Voc)	21.7V
Short circuit current (Isc)	3.99A
Temperature Coefficient of Voc	−8.21×10-2 V/^{o}C
Temperature Coefficient of Isc	1.59×10-3 A /^{o}C
Number of series cells (Ns)	36

Table 2: Solar cell parameters.

Parameter	Value
R_s	0.264 Ω
R_p	42.4 kΩ
a	1.3
I_{ph}	3.99002 A
I_{sat}	5.7452*10^{-8} A

Note: the electrical specifications are under standard test conditions (STC) of irradiance of 1kW/m^2, spectrum of 1.5 air mass and cell temperature of 25 ^{o}C. According to the above specifications, the results shown in table 2 were obtained.

2.2 Selection and Design of Converter

The buck boost converter (BBC) is selected in this paper due to its advantageous [11]. For equal input and output powers, the dc voltage transfer function of the BBC is [3]. Figure 3 shows the schematic diagram of the BBC.

$$\frac{V_o}{V_s} = -\frac{D}{1 - D} \quad (5)$$

where V_s is the dc input voltage source, V_o is the dc output voltage and D is the duty cycle of the switching signal (the D value is between 0 and 1). The value of the inductor that represents the boundary between the continuous and discontinuous current mode (L_B) is [3]

$$L_B = \frac{(1 - D)^2 \, R}{2f_s} \quad (6)$$

where R is the load resistance and f_s is the switching frequency. The switching frequency of high efficiency BBC sued in solar systems is between 20k Hz and 100 kHz [12]. To limit the peak-to peak value of the ripple voltage, the filter capacitance (C) must be greater than its minimum value [3].

$$C_{min} = \frac{DV_o}{V_r f_s R} \quad (7)$$

2.2.1 Input Capacitor Design

To connect the BBC with the PVA, an input capacitor, (C_{in}), must be added to reduce the input current ripple to the required value. In [13], an equation for calculating the input capacitor value of buck converter was presented. This equation is used in this work in order to deduce an equation for calculating the input capacitor value of BBC converter and it is found to be

$$C_{in} \geq \frac{(1 - D_{cm})}{0.02 \, R_{pvm} \, f_s} \qquad (8)$$

Where D_{cm} is the duty cycle at maximum converter output power and R_{pvm} is the PVA internal resistance at the maximum power point. The specifications of the necessary BBC components are listed in table below.

Table 3: BBC components.

Component	Value
L	0.002 mH
C_o	0.2 F
C_{in}	2.2 mF
f_s	25 kHz
R	0.192Ω
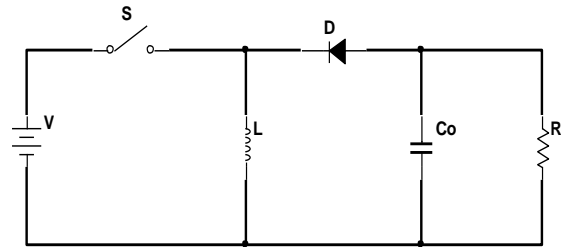
Figure 3: schematic diagram of the BBC.

2.3 MPPT Controller

The temperature and the irradiation level affect on the PV cells efficiency so to increase this efficiency, methods are to be undertaken to match the source and load properly. One such method is the MPPT. This is a technique used to obtain the maximum possible power from a varying source [14]. Many MPPT algorithms are presented such as HC method and IncCond method. HC method is known as direct control method. It works on the same concept as P&O method but it updates the operating point of the PVA by directly perturbing the duty cycle, d(k), instead of perturb the voltage as shown in figure 4 [11]. The approach greatly simplifies the control structure because it eliminates the need for the proportional integral (PI) which is normally employed to control the duty cycle with reference to voltage.

The IncCond algorithm seeks to overcome the limitations of the P&O algorithm by using the PV array's incremental conductance to compute the sign of dP/dV (or $dI/dV = - I/V$) without a perturbation. This algorithm has advantages over P&O algorithm in that it can determine when the MPPT has reached the MPP, while P&O algorithm oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than P&O. One disadvantage of this algorithm is the increased complexity when compared to P&O and this increases computational time [15, 16].
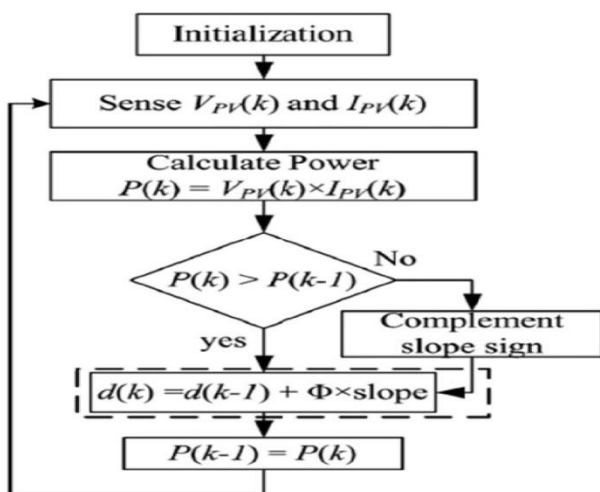

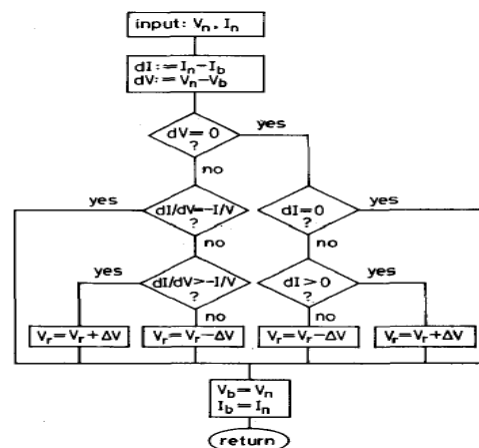**Figure 4: Flow chart of the conventional HC method.**

Figure 5: Flow chart of IncCond method.

2.4 BTS LOAD

A mathematical equation to determine the power consumption of BTS site was developed [17]. This equation indicates that the total power consumption could be evaluated when the power consumption of each base station component is known, and according to this, the power consumption of one sector base station with one antenna was found to

$$P_{BTS} = n_{sector} * (P_{DSP} + n_{TR} * (P_{Amp} + P_{Tran}) + P_{Rec}) + \sum_{i}^{n} P_{AC_i} + \sum_{k}^{l} P_{micro} + \sum_{j}^{m} P_{LB_j} \qquad (9)$$

where n_{sector} is the number of sectors in the cell, n_{TR} is the number of transmitting antennas per sector and P_{BTS}, P_{DSP}, P_{Amp}, P_{Tran}, P_{Rec}, P_{AC}, P_{micro} and P_{LB} is the total power consumption of the base transceiver station, digital signal processing, power amplifier, transceiver, rectifier, air conditions, microwave and incandescent bulbs respectively where l, n and m represents the total number of microwaves, AC's and bulbs in the site.

The proposed system considered installing MOTOROLA (Horizon II macro) equipment, with (-48V and 99A maximum voltage and current respectively) i.e. maximum power of 4752 W, used in BTS cabinet. The power consumption by one AC unit, one microwave link and three incandescent bulbs is 2400 W, 80 and 180 respectively. In addition to these requirements, AC unit needs additional power for steady state operation [18] therefore, 12 kW is required to meet the occasional peak power for starting air conditioning unit.

3. Simulation Results

3.1 Implementation of PVA

A (N_{ss}=5 and $N_{pp=}$ 37) PVA was designed in order to support the load with its power demand (12kW). The design was implemented using matlab imbedded function. The PVA performance was examined under different ambient conditions. Temperature and irradiation level changing produced changing in the PVA characteristic, as the temperature increased, the output power from PVA is decreased and vice versa while increasing Irradiation level causes increasing in PV output power and vice versa as shown in figures below.
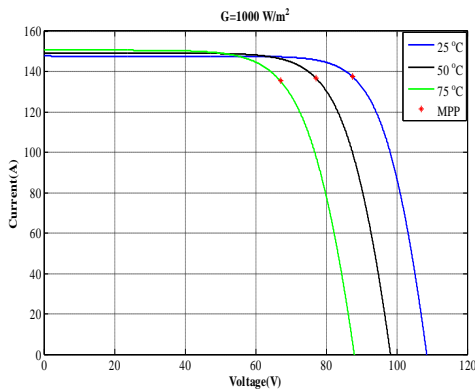

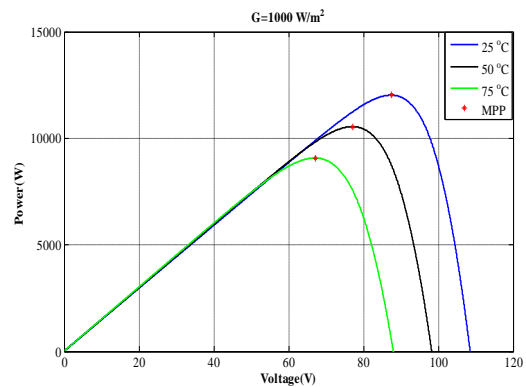**Figure 6: I-V curves of the PVA at different temperature level.**

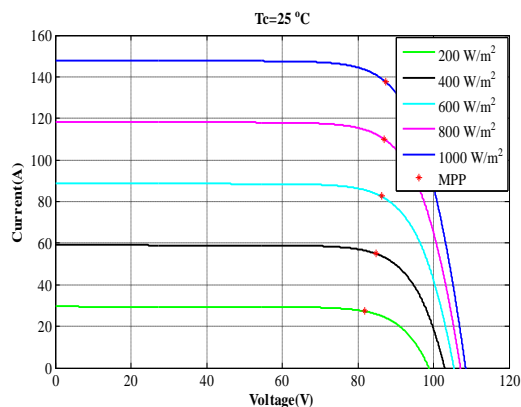**Figure 7: P-V curves of the PVA at different temperature level.**

Figure 8: I-V curves of the PVA at different insolation levels.
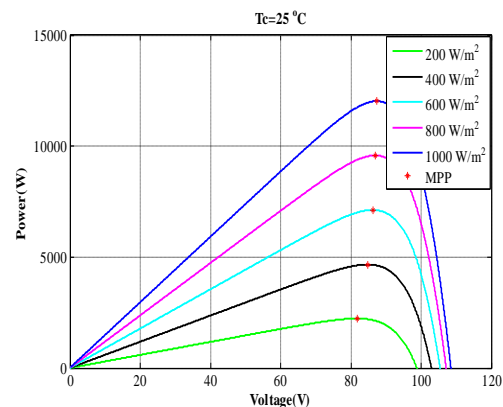

Figure 9: P-V curves of the PVA at different insolation levels.

3.2 Simulation Results of the Complete Tracking System

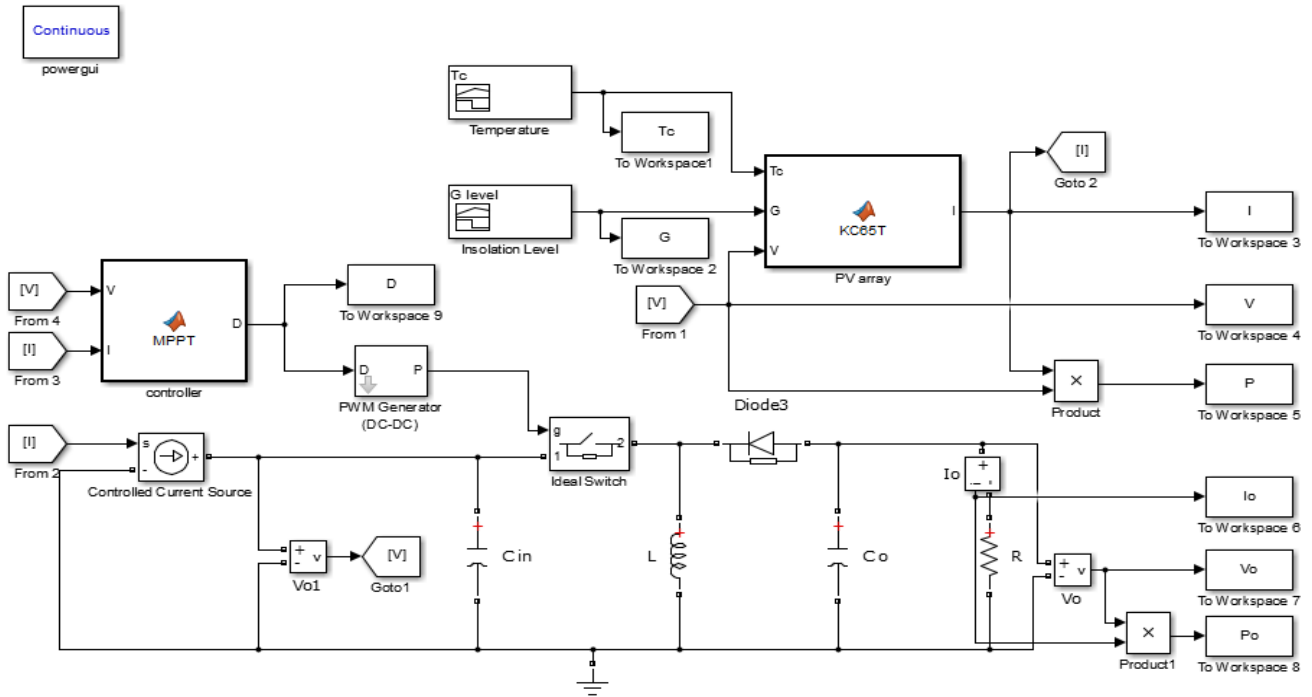The complete tracking system was implemented as shown in figure below.

Figure 10: Simulink implementation of the complete tracking system.

Simulation appeared that there is no significant difference between the two algorithms at STC while IncCond method becomes faster than HC method at fast insolation level changing as shown in figures below.
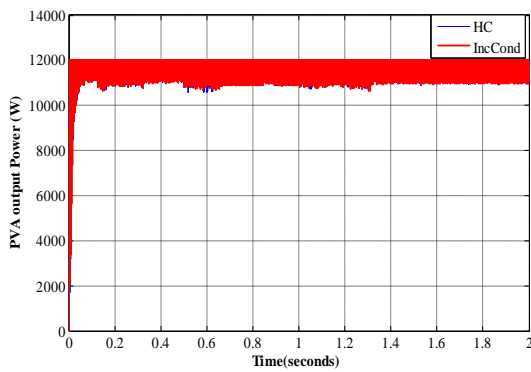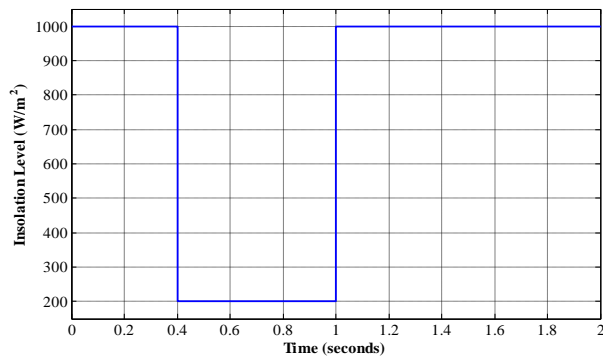

Figure 11: PVA output power comparison

At STC.

Figure 12: Insolation level variation.
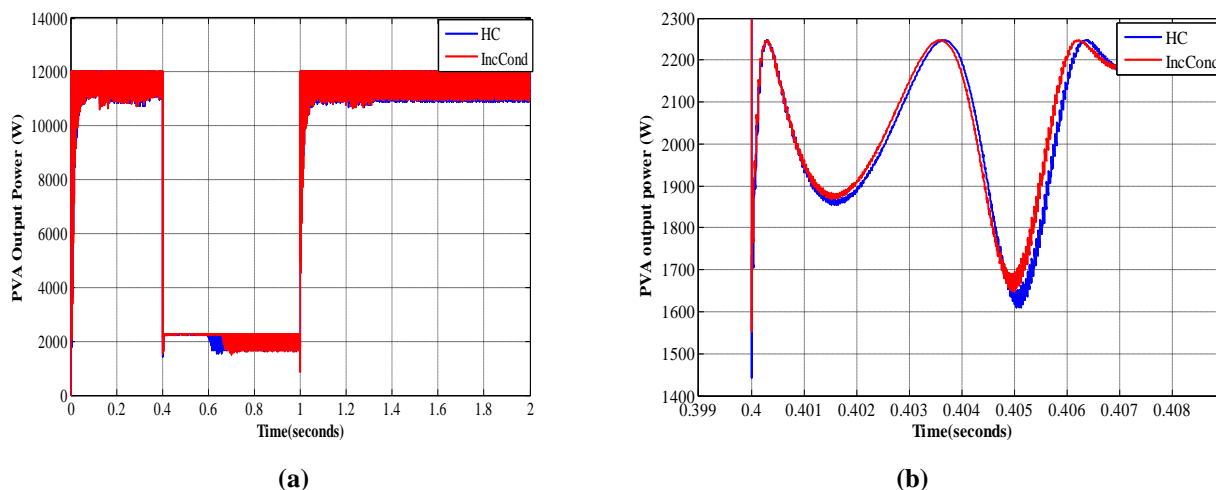
(a)   (b)

Figure 13: PVA output power at insolation level changing (a) Comparison between two states of output power (b) Scope of the comparison.

A small tolerance (ε=0.01) for the power condition (i.e. *dP/dV*=0.01) made the IncCond algorithm faster, minimized the losses in power and vanished the oscillation around the MPP at 200 W/m^2 insolation level as shown in figure below
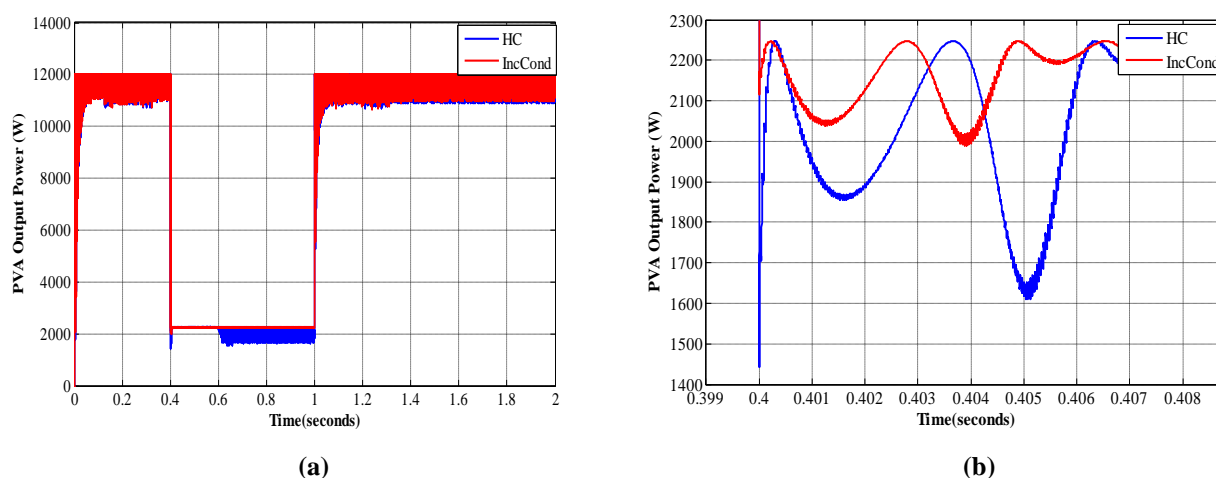

(a)   (b)

Figure 14: PVA output power at insolation level changing after IncCond algorithm modification (a) Comparison between two states of output power (b) Scope of the comparison.

4. Conclusions

In this paper, a tracking system is implemented to harvest the maximum power from PVA using HC and IncCond controller algorithms. The characteristics curves of PVA have been matched with the theoretical prediction. The input capacitor of the BBC is very important to minimize the ripple of PVA output current as well as it is gives a solution for the high starting inductor current problem. Also the two MPPT algorithms can track the MPP successfully at any instant of ambient factor changing and the IncCond algorithm becomes faster with minimum losses in power than the HC algorithm at fast changing conditions especially when a proper tolerance for power condition is used.

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