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A New Study of Maximum Power Point Tracker Techniques and Comparison for PV Systems

Ahmed M. Atallah[1] , Almoataz Y. Abdelaziz[2] , Raihan S. Jumaah[3]
[1,2,3] Electrical power & Machine Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

Abstract

The maximum power point tracker techniques vary in many aspects as simplicity, digital or analogical implementation, sensor required, convergence speed, range of effectiveness, implementation hardware, popularity, cost and in other aspects. This paper presents in details comparative study between two most popular algorithm technique which is incremental conductance algorithm and perturb and observe algorithm. Two different converters buck and cuk converter use for comparative in this study. Few comparisons such as efficiency, voltage, current and power output for each different combination have been recorded. Multi changes in irradiance, temperature by keeping voltage and current as main sensed parameter been done in the simulation. Matlab simulink tools have been used for performance evaluation on energy point. Simulation will consider different solar irradiance and temperature variations.

Keywords: Maximum power point tracking (MPPT), Photovoltaic (PV), DC-DC converters.

دراسة جديدة في تقنيات تتبع نقطة القدرة العظمى والمفارنة في منظومات الخلايا الشمسية

الخلاصة

ان تقنيات تتبع نقطة القدرة العظمى في منظومات الخلايا الشمسية تختلف عن بعضها في عدة جوانب مثل بساطة التقنيات ونوع تطبيقها رقمية او غير رقمية وعدد ونوع المتحسسات المطلوبة وسرعة التحويل ومعدل فعاليتها والاجهزة المستخدمة وشهرتها وكذلك كلفة التقنية المستخدمة بالاضافة الى جوانب اخرى، وفي هذا البحث تم اعداد دراسة جديدة لتتبع نقطة القدرة العظمى وتتمثل بتطبيق اشهر طريقين وهما (P&O and IC Algorithms) باستخدام محولين تيار مستمر-تيار مستمر وهما (Buck & Cuk). وقد اجريت المقارنة على النتائج التي تم الحصول عليها من المحاكاة كالكفاءة والفولتية والتيار وكذالك القدرة الخارجة ، واعتمدت الدراسة على تاثير تغير كمية الاشعاع الشمسي، وهذه النتائج سجلت لكل منظومة متداخلة او مشتركة مع منظومات الخلايا الشمسية واجريت الدراسة وذلك باستخدام المحاكاة والادوات الموجودة في برنامج ماتلاب.

الكلمات الدالة: متتبع نقطة القدرة العظمى، منظومة خلايا شمسية، ومحول تيار مستمر.

Introduction

The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions. Solar energy has offered promising results in the quest of finding the solution to the problem. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the photovoltaic (PV) modules [1,2,3]. A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solve the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers [1,2,3]. As the market is now flooded with varieties of these MPPT that are meant to improve the efficiency of PV modules under various insolation conditions it is not known how many of these can really deliver on their promise under a variety of field conditions.

This research then looks at how a different type of converter affects the output power of the module and also investigates if the MPPT that are said to be highly efficient and do track the true maximum power point under the various conditions [1]. A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load [4,5]. A dc/dc converter (step up/ step down) serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the module, Figure (1) [5]. By changing the duty cycle the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power [5]. Therefore MPPT techniques are needed to maintain the PV array's operating at its MPP [6], Figure (2). Many MPPT techniques have been proposed in the literature; example are the Perturb and Observe (P&O) methods [4,6,7,8,9], Incremental Conductance (IC) methods [7,10,11,12], Fuzzy Logic Method [2,4,6,11], etc.

In this paper two most popular of MPPT techniques (Perturb and Observe (P&O) methods and Incremental Conductance methods (IC)) and different DC-DC converter (Buck and Cuk converters) will be involved in comparative study [13]. Few comparisons such as voltage, current and power output for each different combination have been recorded. Multi changes in duty cycle, irradiance, temperature by keeping voltage and current as main sensed parameter been done in the simulation. The MPPT techniques will be compared, by using Matlab tool Simulink, considering the variant of circuit combination.

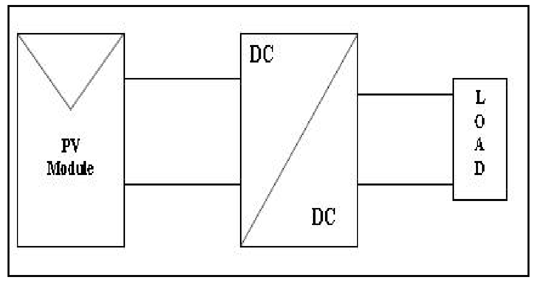

Fig. 1. Block diagram of Typical MPPT system

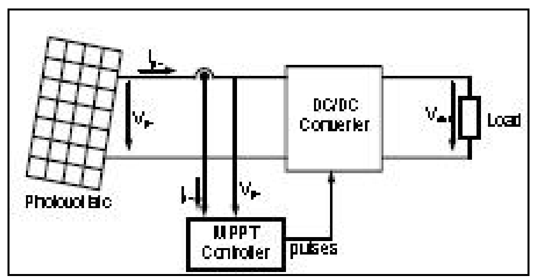

Fig. 2. DC - DC converter for operation at the MPP

PV Array

A solar panel cell basically is a p-n semiconductor junction .When exposed to the light, a DC current is generated. The generated current varies linearly with the solar irradiance [14]. The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode shown in Figure (3).

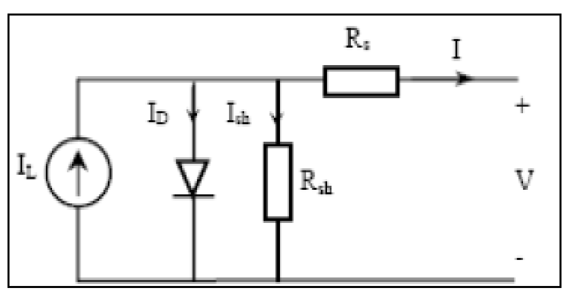

Fig. 3. Equivalent electrical circuit of a solar cell

The I-V characteristics of the equivalent solar cell circuit can be determined by following equations [14]. The current through diode is given by:

ID = IO [exp (q(V + IRS)/KT)) - 1] …..…..….(1)

While, the solar cell output current:

I = IL - ID – Ish ……………………………… (2)

I = IL - IO [exp (q (V + IRS)/KT)) -1] - (V + IRS) / Rsh …………………………………… (3)

Where:
I: Solar cell current (A)
IL: Light generated current (A) [Short circuit value assuming no series/ shunt resistance]
Io: Diode saturation current (A)
q: Electron charge (1.6×10-19 C) K : Boltzmann constant (1.38×10-23 J/K) T : Cell temperature in Kelvin (K) V : solar cell output voltage (V)
Rs: Solar cell series resistance (Ω)
R: Solar cell shunt resistance (Ω)

DC-DC Converter

Buck Converter

The buck converter can be found in the literature as the step down converter [15]. This gives a hint of its typical application of converting its input voltage into a lower output voltage, where the conversion ratio M = Vo/Vi varies with the duty ratio D of the switch [15,16]. The Ideal buck converter circuit shown in Figure (4).

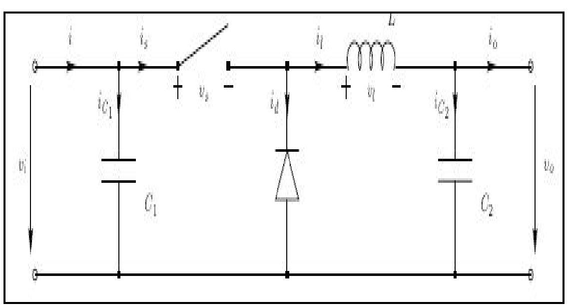

Fig. 4. Ideal buck converter circuit

Cuk Converter

The Cuk converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. Cuk converter will responsible to inverter the output signal from positive to negative or vise versa. Figure (5) shows the equivalent circuit of Cuk Converter.

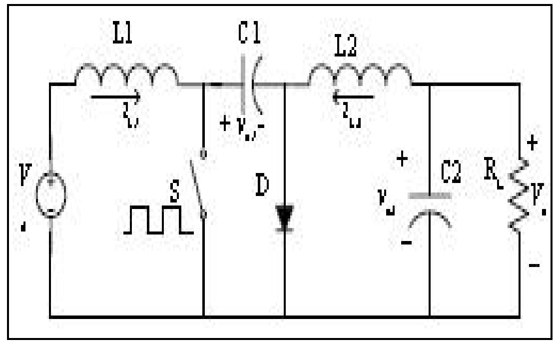

Fig. 5. Equivalent Circuit of Cuk Converter

Problem Overview

The problem considered by MPPT techniques is to automatically find the voltage VMPP or current IMPP at which a PV array should operate to obtain the maximum power output PMPP under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic fine tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array [6,11,14,15].

Maximum Power Point Tracker Control Algorithms

Perturb and Observe (P&O)

In perturb and observe algorithm, as shown in Figure (6), a slight perturbation is introduce system, This perturbation causes the power of the solar module changes. If the power increases due to the perturbation then the perturbation is continued in that direction [7]. After, the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses. When the steady state is reached the algorithm oscillates around the peak point. To keep small power varies the perturbation size is kept very small. The algorithm is developed in such a manner that it sets a reference voltage of the module corresponding to the peak voltage of the module. A PI controller then acts moving the operating point of the module to that particular voltage level. It is observed that there some power loss due to this perturbation also the fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular and simple [7].

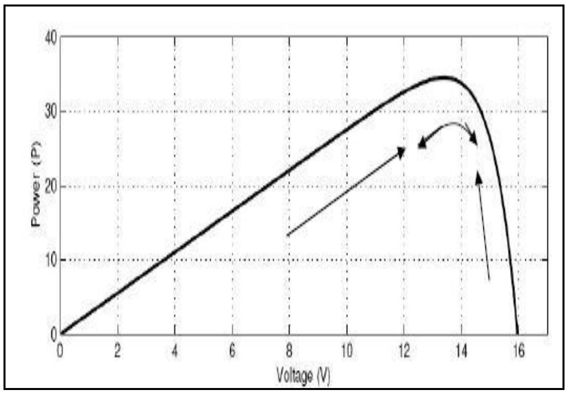

Fig. 6-a. Graph Power versus Voltage for Perturb and Observe Algorithm [7]

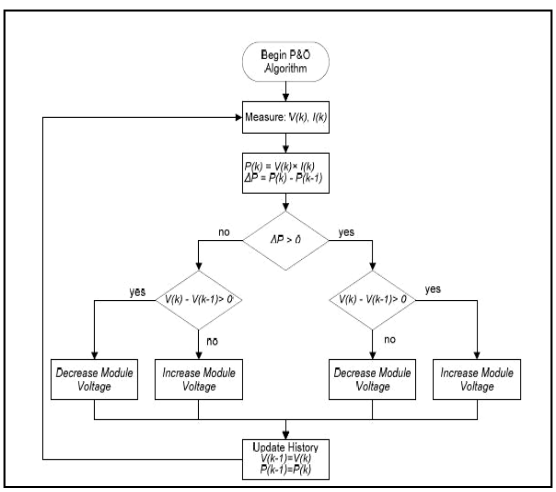

Fig. 6-b. Perturb and Observe Algorithm [17]

Incremental Conductance (IC)

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method [7,18]. The IC, Figure (7), can determine that the MPPT has reached the MPP and stop perturbing the **operating point.** If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dI/dV and -I/V [7]. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe. One disadvantage of this algorithm is the increased complexity when compared to P&O [7, 19].

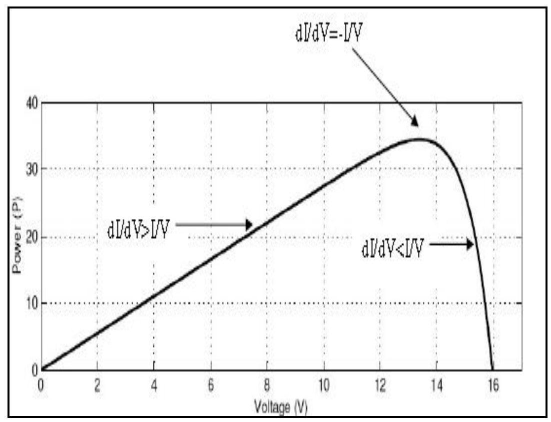

Fig. 7-a. Graph Power versus Voltage for IC Algorithm [7]

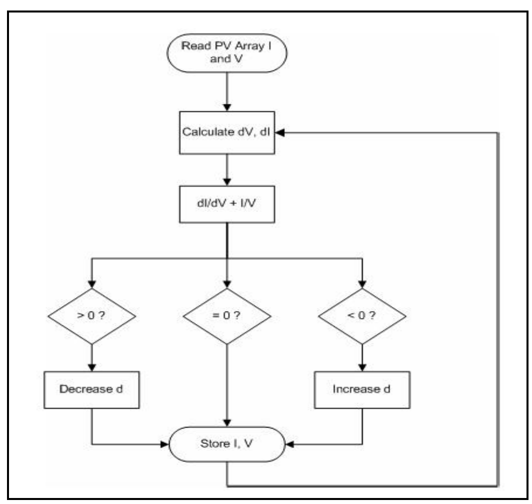

Fig. 7-b. IC Algorithm [7]

Graphical Environment

Matlab Simulink Environment

The solar PV module circuit represented by the simulink matlab tool as shown in Figure (8),but the module of buck and cuk converter can be represent as shown in Figures (9) and (10).

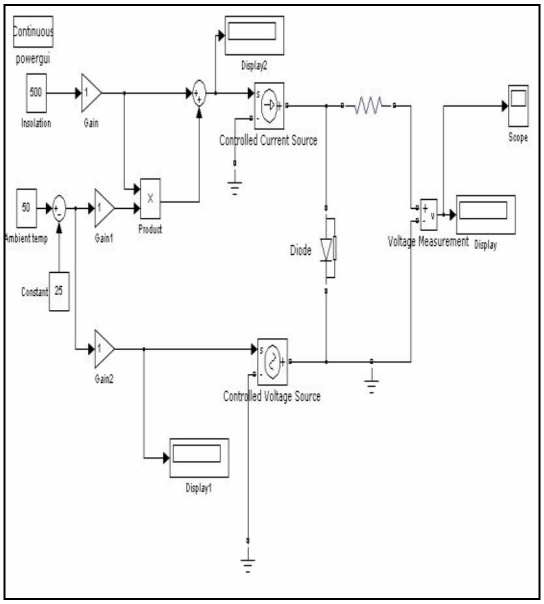

Fig. 8. Simulink model of the solar PV module

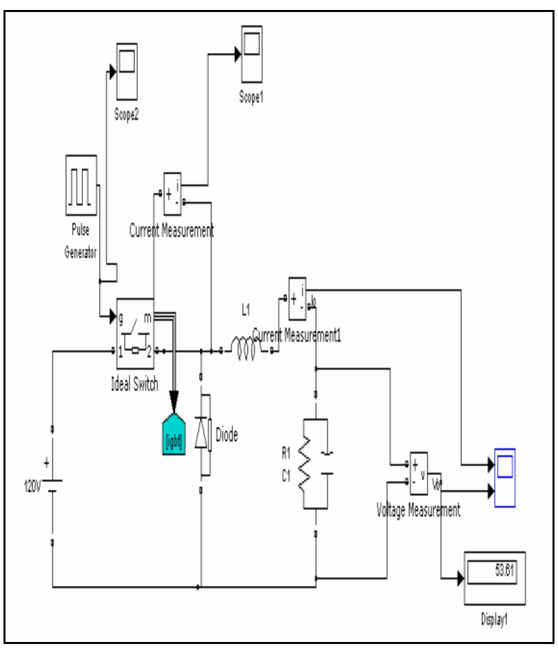

Fig. 9. Simulink model of buck converter

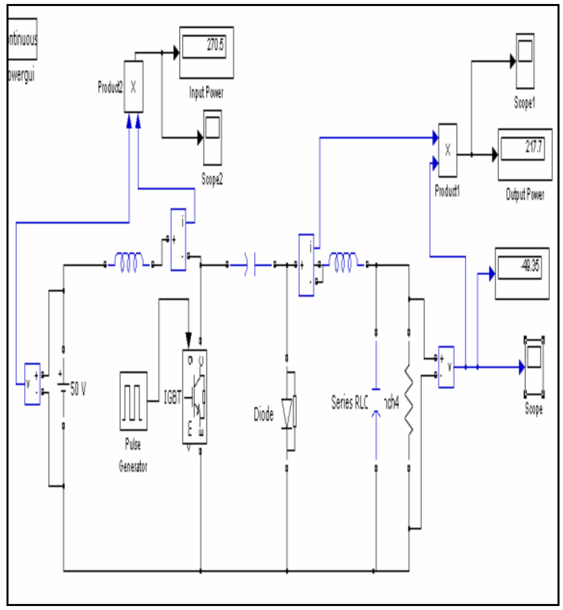

Fig. 10. Simulink model of cuk converter

Results and Simulation

The simulation and results for every converter have been recorded to make sure the comparison of the circuit can be determined accurately. The input, output, voltage, current and power is the main comparison to take into consideration. The complexity and simplicity of the circuit have been determined based on the literature. Convergence speed, hardware required and range of effectiveness [4,6].

PV Panel Simulation

The output voltage, current and power results of PV panel have been simulated and recorded as shown in Figure (11) and Table (1).

Table 1. Output Value for PV panel

Output voltage	Output current	Output power
28.4 V	2.84 A	80.64 W

Result for insolation = 100 and temperature = 49˚

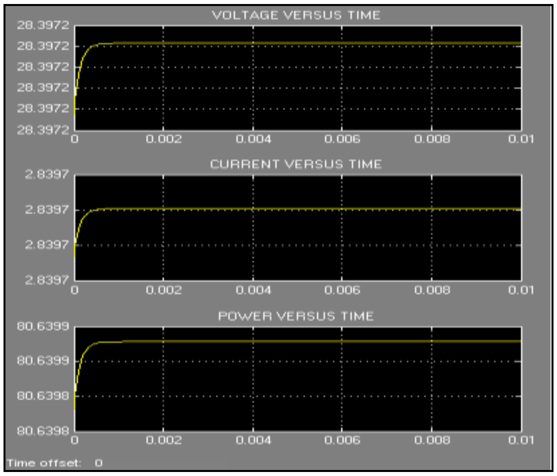

Fig. 11. Output voltage, current and power for PV panel

Comparison between Buck and Cuk Converter

From Table (2), the calculated theoretical results and simulation results can be observed. The percentage between theoretical value and experimental value difference type of curve. Theoretical value calculated from the basic equation of converters. This involved the calculation when selection of component. Meanwhile the experimental value is from the simulation result using MATLAB simulink environment. In this comparison show that buck converter will give the best simulation result, follow by cuk converter. All of this converter will be used in comparing two basic controllers in MPPT.

Table 2. Theoretical value and simulation value of Buck and Cuk

Converter	Analysis	Theoretical Value(V)	Simulation Value(V)	Percentage Difference (%)
Buck	V in	12	12	0
	V out	5	5.087	1.74
Cuk	V in	14	14	0
	V out	-12	-8.595	28

Comparison of Perturb & Observe Controller and Incremental Conductance in Buck Converter

Buck Converter Simulation with Perturb & Observe and incremental conductance Controllers Output current and voltage have been simulated as shown in Figures (12) and (13). Table (3) shows the overall comparison for P&O and IC Controller. Once the converter injected the power from the solar panel and the controller start function, the value for of Vin to controller do not same value from output of the solar panel. This is because the controller function that varies the value of duty cycle will change the input value that sense by the controller. The input voltages of this controller show a different each other. Buck the connected with P&O give a value of 26.8V, therefore buck that connected with incremental conductance give value of 17.87V. In incremental conductance controller the output voltage and current is not change between input and output value. The perturb and observe controller give a difference for input and output value. The output values behave as buck converter behaves. The voltage will drop from 26.8V to 16.8V and finally the voltage value is 534mV. In this system show that incremental conductance controller will work better with buck controller than perturb and observe controller. The incremental conductance controller will have the stable value from start to end of the simulation.

Table 3. Comparison output value between perturb & observe and incremental conductance in Buck Converter

Controller	Vin(V)	Iin(A)	Vout1(V)	Vout2(V)	Iout1(A)	Iout2(A)
P&O	26.8	0.97	16.8	0.0534	0.97	0.007
IC	17.9	0.84	17.87	17.87	0.84	0.8391

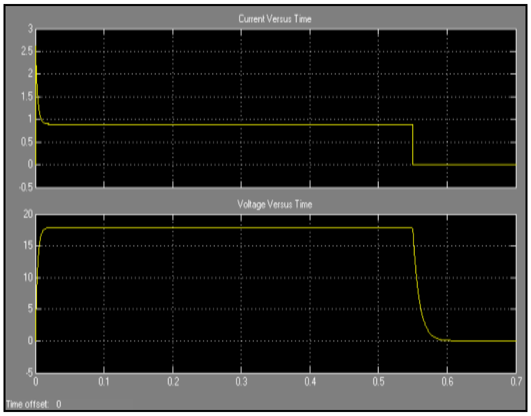

Fig. 12. Output current and voltage for Buck and P&O controller

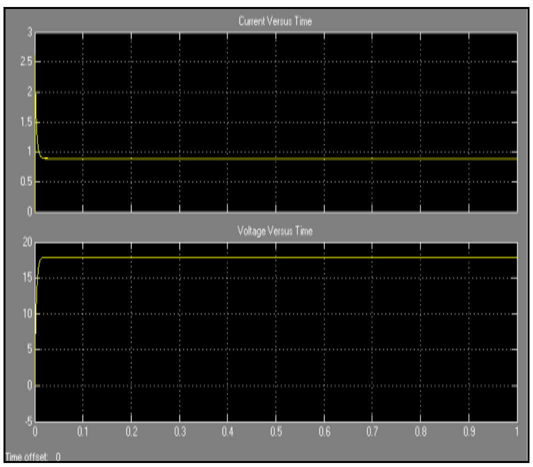

Fig. 13. Output current and voltage for Buck and In Con controller

Comparison of Perturb & Observe Controller and Incremental Conductance in Cuk Converter

Cuk Converter Simulation With Perturb & Observe and incremental conductance Controllers Output current and voltage have been simulated as shown in Figures (14) and (15). Table 4 shows the comparison between P&O Controller and IC Controller. From the simulation the input voltage from PV panel to the controller and the converter give almost the same value. The input current for this circuit give big value of current, 2600 A and this value is same for both controller. Incremental conductance controller will give the negative value of Current and voltage and this will cause the positive power output.

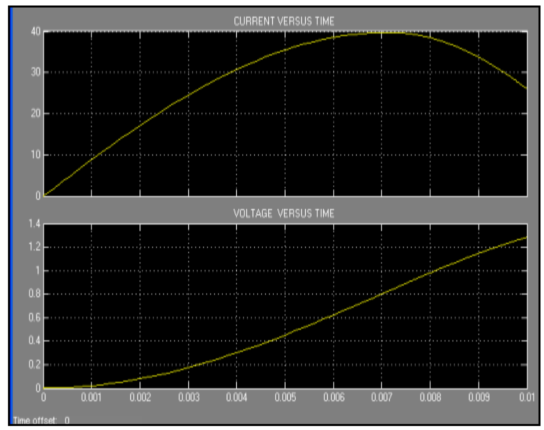

Fig. 14. Output current and voltage for Cuk and P&O controller

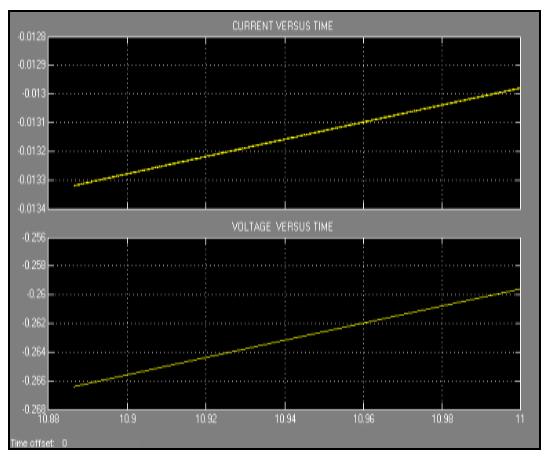

Fig. 15. Output current and voltage for Cuk and IC controller

Table 4. Comparison output value between perturb & observe and incremental conductance in Cuk Converter

Controller	Vin(V)	Iin(A)	Vout(V)	Iout(A)
P&O	3.536	2600	1.283	26
IC	3.642	2600	-0.26	-0.013

Conclusions

This paper presented a comparison of two most popular MPPT controllers, perturb and observe controller with incremental conductance controller. This paper focus on comparison of two different converters which will be connected with the controller. One simple solar panel that has standard value of insolation and temperature has been included in the simulation circuit. From all the cases, the best controller for MPPT is incremental conductance controller. This controller gives a better output value for buck and cuk converter. Hence this controller will give different kind of curves for the entire converter. In simulation Buck converter show the best performance the controller work at the best condition using buck controller.

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