Comparison Study of Maximum Power Point Tracker Techniques for PV Systems

Hairul Nissah Zainudin
Center of Foundation in Sciences,
CyberjayaUniversity College of Medical Sciences,
Cyberjaya, Selangor, Malaysia.
hairulnisa@cybermed.edu.my

Saad Mekhilef
Department of Electrical Engineering,
University of Malaya
Kuala Lumpur, Malaysia.
saad@um.edu.my

Abstract -**These 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 algorithms technique which is incremental conductance algorithm and perturb and observe algorithm. Three different converter buck, boost and cuk converter use for comparative in this study. Few comparison such as efficiency, voltage, current and power out put for each different combination has 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.**

Keyword: **maximum power point tracking, MPPT, photovoltaic, PV, direct current, DC**

I. 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 PV modules[1-3].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 [1-3]. 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]. Many MPPT techniques have been proposed in the literature; example are the Perturb and Observe (P&O) methods [4, 6-9], Incremental Conductance (IC) methods [7, 10-12], Fuzzy Logic Method [2, 4, 6, 11], etc. In this paper two most popular of MPPT technique (Perturb and Observe (P&O) methods and Incremental Conductance methods) and three

different DC-DC converter (Buck, Boost and Cuk converter) will involve in comparative study. Figure 2 [13]
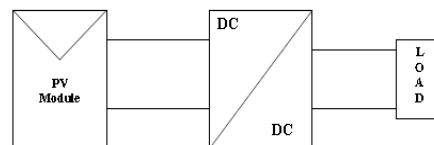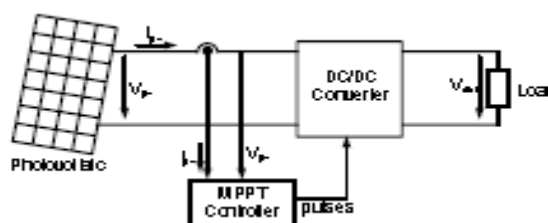

Fig. 1: Block diagram of Typical MPPT system

Fig. 2: DC – DC converter for operation at the MPP

Few comparison such as voltage, current and power out put for each different combination has 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.

II.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.
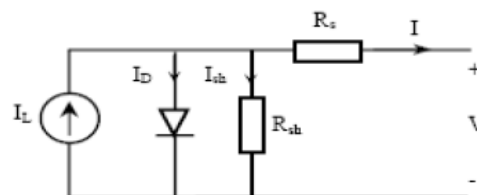

Fig. 3: Equivalent electrical circuit of a solar cell

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

$$I_D = I_O \left[\exp \left(q(V + I R_S)/KT \right) - 1 \right] \tag{1}$$

While, the solar cell output current:

$$I = I_L - I_D - I_{sh} \tag{2}$$

$$I = I_L - I_O \left[\exp\left(q(V + I\,R_S)/KT\right) - 1 \right] - (V + IR_S)/R_{sh} \quad (3)$$

Where:

I : Solar cell current (A)

I : Light generated current (A) [Short circuit value assuming no series/ shunt resistance]

I_O : Diode saturation current (A)

q : Electron charge (1.6×10-19 C)

K : Boltzman constant (1.38×10-23 J/K)

T : Cell temperature in Kelvin (K)

V : solar cell output voltage (V)

R_s : Solar cell series resistance (Ω)

R_{sh} : Solar cell shunt resistance (Ω)

III. DC-DC CONVERTER

A. 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 = V_o/V_i varies with the duty ratio D of the switch [15, 16].
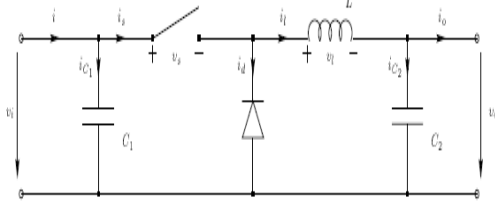

Fig. 4: Ideal buck converter circuit

B. Boost Converter

The boost converter is also known as the step-up converter. The name implies its typically application of converting a low input-voltage to a high out-put voltage, essentially functioning like a reversed buck converter [15, 16].
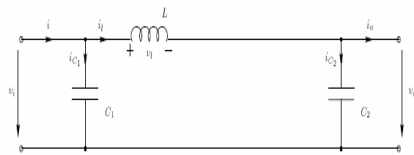

Fig. 5: Equivalent Circuit of a Boost Converter

C. 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.
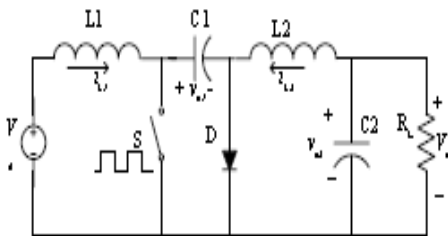

Fig. 6: Equivalent Circuit of Cuk Converter

IV. PROBLEM OVERVIEW

The problem considered by MPPT techniques is to automatically find the voltage V_{MPP} or current I_{MPP} at which a PV array should operate to obtain the maximum power output P_{MPP} 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].

MPPT CONTROL ALGHORITHM

A. Perturb and Observe (P&O)

In this algorithm a slight perturbation is introduce system [7]. 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. In order to keep the power variation small 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].
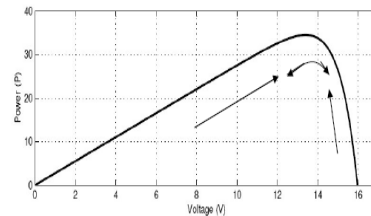

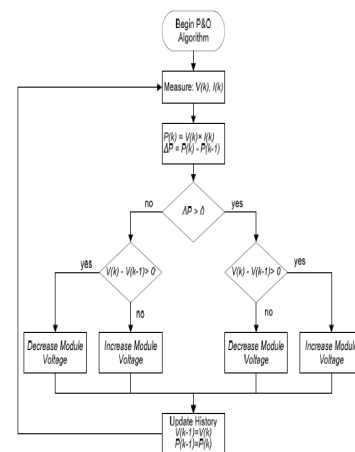Fig. 7(a): Graph Power versus Voltage for Perturb and Observe Algorithm [7]

Fig. 7(b): Perturb and Observe Algorithm [17]

B. 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 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 [7, 19]. One disadvantage of this algorithm is the increased complexity when compared to P&O [7, 19].
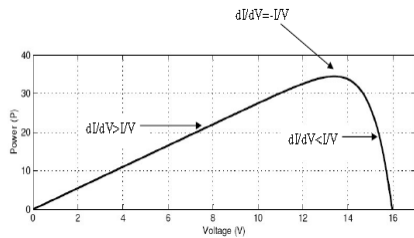
751

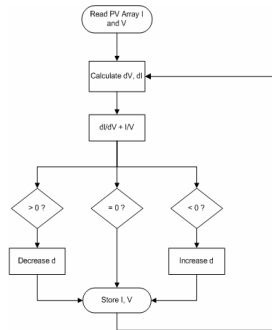Fig. 8(a): Graph Power versus Voltage for IC Algorithm [7]
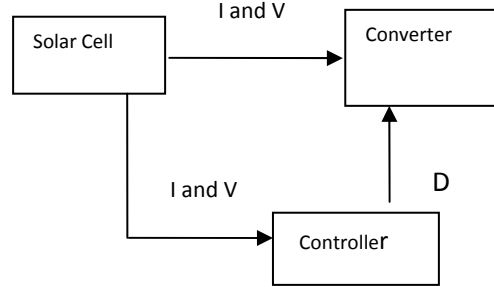

Fig. 8(b): IC Algorithm [7]

C. Parasitic capacitances [7]

The parasitic capacitance method is a refinement of the incremental conductance method that takes into account the parasitic capacitances of the solar cells in the PV array. Parasitic capacitance uses the switching ripple of the MPPT to perturb the array. To account for the parasitic capacitance, the average ripple in the array power and voltage, generated by the switching frequency, are measured using a series of filters and multipliers and then used to calculate the array conductance [20]. The incremental conductance algorithm is then used to determine the direction to move the operating point of the MPPT. One disadvantage of this algorithm is that the parasitic capacitance in each module is very small, and will only come into play in large PV arrays where several module strings are connected in parallel. Also, the DC-DC converter has a sizable input capacitor used filter out small ripple in the array power. This capacitor may mask the overall effects of the parasitic capacitance of the PV array.

D. Voltage control maximum point tracker

It is assumed that a maximum power point of a particular solar PV module lies at about 0.75 times the open circuit voltage of the module. So by measuring the open circuit voltage a reference voltage can be generated and feed forward voltage control scheme can be implemented to bring the solar PV module voltage to the point of maximum power. One problem of this technique is the open circuit voltage of the module varies with the temperature. So as the temperature increases the module open circuit voltage changes and we have to measure the open [6, 21, 22]
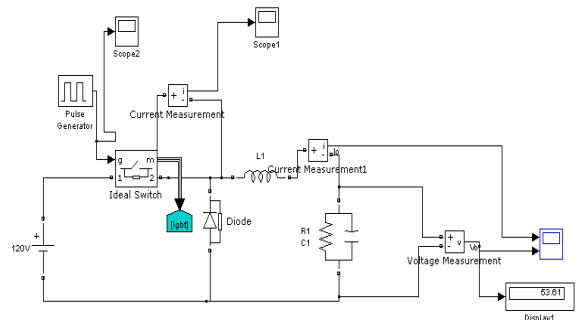
V. GRAPHICAL ENVIRONMENT

MATLAB SIMULINK ENVIRONMENT

Fig.9: Basic Block Diagram for MPPT

Fig.10:Simulink model of the solar PV module.

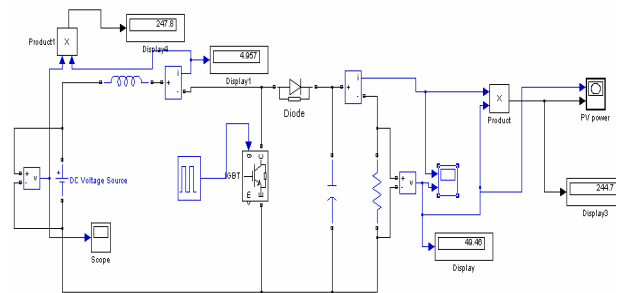Fig 11:Simulink model of buck converter.

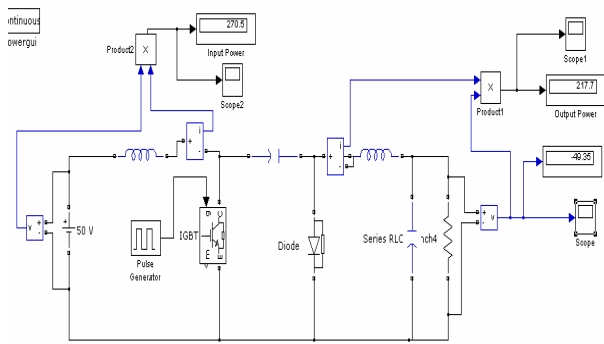Fig 12:Simulink model of boost converter.
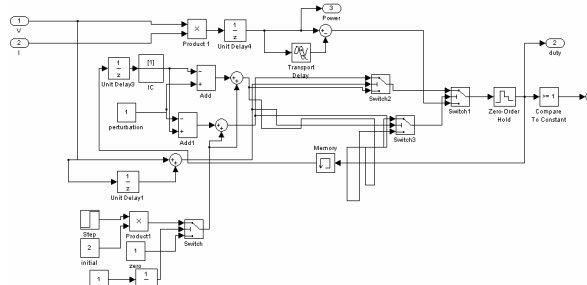
752

Fig 13:Simulink model of cuk converter.

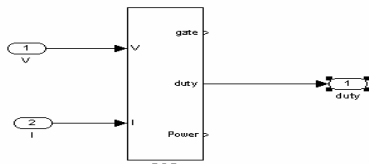Fig. 14: Simulink model for P&O Alghorithm

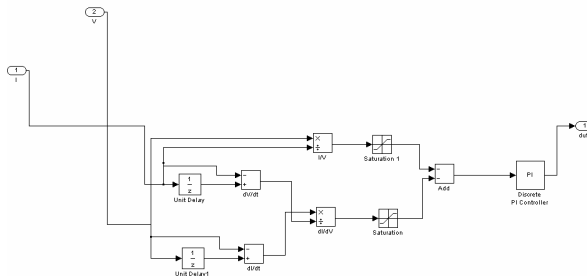Fig. 15: Simulink model for Subsystem P&O Alghorithm
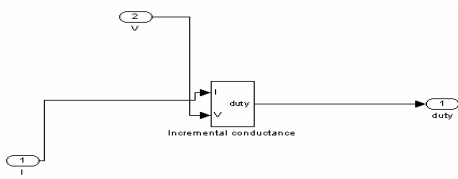

Fig. 16: Simulink model for IC Alghorithm

Fig. 17: Simulink model for Subsystem IC Alghorithm

VI. RESULTS AND SIMULATION

All simulation and result 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]. Figure 18 take an insolation of 100 and temperature 50 as initial value.

A. PV Panel Simulation
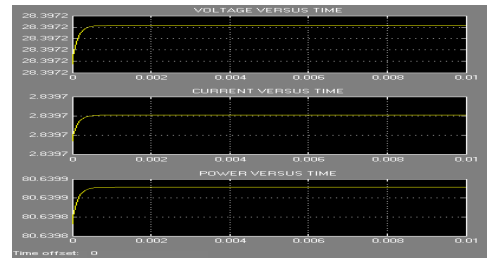
Fig. 18: Output Voltage, Current and Power for PV panel

Table 1: Output Value for PV Panel

Output Voltage	Output Current	Output Power
28.4 V	2.84 V	80.64 W

Result for insolation = 100 and temperature = 50 degree.

B Converter Simulation

Fig 19: Output current and voltage for Buck Converter

Fig 20: Output current and voltage for Boost Converter

Fig.21: Output current and voltage for Cuk Conveter

Table 2 show the comparison between three converter in theoretical and simulation value

753

Table 2: Theoretical Value and Simulation Value of Buck, Boost and Cuk

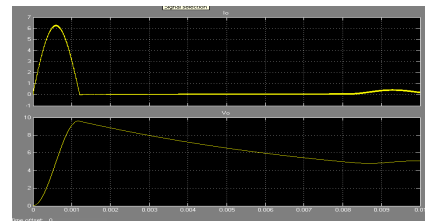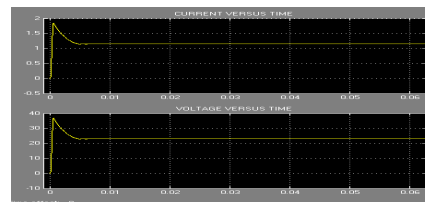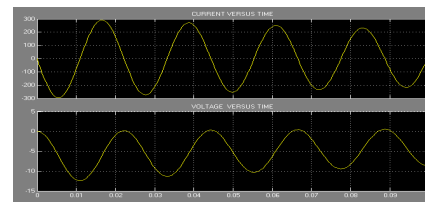| Converter	Analysis	Theoretical Value	Simulation Value	Percentage Difference
Buck	Vin	12 V	12 V	0 %
	Vout	5 V	5.087 V	1.74 %
Boost	Vin	12 V	12 V	0 %
	Vout	24 V	21.92 V	8.7%
Cuk	Vin	14 V	14 V	0 %
	Vout	-12 V	- 8.595 V	28 %

COMPARISON BETWEEN BUCK, BOOST AND CUK CONVERTER

From table 2 calculate theoretical result and simulation result can be observe. The percentage between theoretical value and experimental value also can be seen from the simulation output. All three simulations give 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 boost converter and last is cuk converter. All of this converter will be used in comparing two basic controller in MPPT.

COMPARISON OF PERTURB & OBSERVE CONTROLLER AND INCREMENTAL CONDUCTANCE IN BUCK CONVERTER

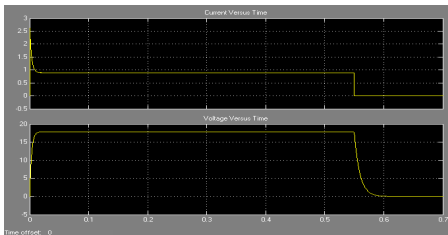C Buck Converter Simulation With Perturb and Observe Controller

Fig 22: Output current and voltage for Buck and P&O Controller

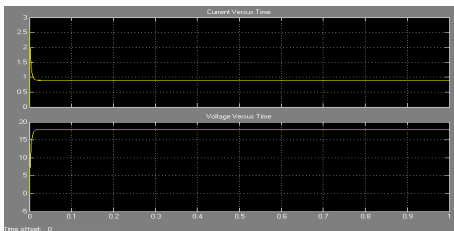D Buck Converter Simulation With Incremental Conductance Controller

Fig 23: Output current and voltage for Buck and In Con Controller

Table 3 show 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 V_{in} 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 26.8 V 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 value behave as Buck converter behave. 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	V_{in} V)	I_{in} (A)	V_{out1} (V)	V_{out2}(V)	I_{out1} (A)	I_{out2} (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

COMPARISON OF PERTURB & OBSERVE CONTROLLER AND INCREMENTAL CONDUCTANCE IN BOOST CONVERTER
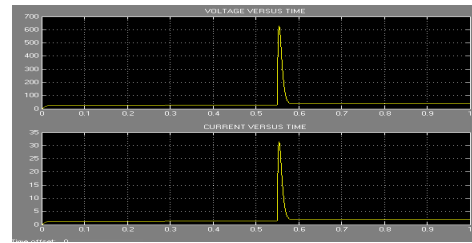
E Boost Converter Simulation With P&O Controller

Fig 24: Output current and voltage for Boost and P&O Controller

F Boost Converter Simulation With Incremental Conductance Controller

Fig 25: Output current and voltage for Boost and IC Controller

Table 4: Comparison Output Value Between Perturb & Observe and Incremental Conductance in Boost Converter

CONTROLLER	V_{in}	I_{in}	V_{out1}	I_{out1}
P&O	38.79 V	1.9 A	37.99 V	1.9 A
IC	38.62V	175.3A	29.92 V	1.496 A

From the simulation show that voltage input for both controller is almost the same. Perturb and Observe Controller shows a not stable condition. During the simulation the current and voltage decrease rapidly and lastly came to same value at the initial stage. From the simulation result is shows that controller that connected with Boost converter which will give a stable output is the incremental conductance controller. Perturb and Observe controller can

achieve maximum output value at 37.99 V that better than incremental conductance controller.

COMPARISON OF PERTURB & OBSERVE CONTROLLER AND INCREMENTAL CONDUCTANCE IN CUK CONVERTER

G Cuk Converter Simulation With Perturb and Observe Controller

Fig 26: Output current and voltage for Cuk and P&O Controller

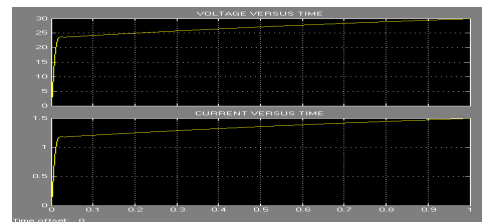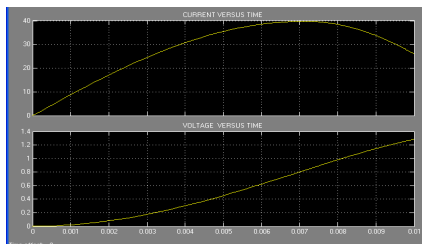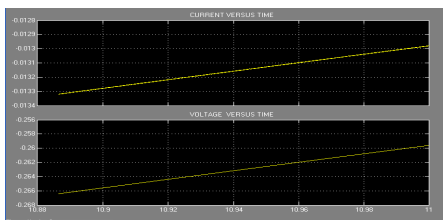### H Cuk Converter Simulation With Incremental Conductance Controller

Fig 27: Output current and voltage for Cuk and IC Controller

CONTROLLER	V_{in}	I_{in}	V_{out}	I_{out}
P&O	3.536V	2600A	1.283 V	26A
INC. COND	3.642V	2600A	-0.26 V	-0.013A

Table 5: Comparison Output Value Between Perturb & Observe and Incremental Conductance in Cuk Converter

Table 5 shows the comparison between PO 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.

CONCLUSION

This paper has presented a comparison of two most popular MPPT controller, Perturb and Observe Controller with Incremental Conductance Controller. This paper focus on comparison of three different converter which will 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, boost 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.

REFERENCES

[1] R. S.Lewis, "Antartic Research and Relevant of Science," in *Bulletin of the Atomic Scientists*, vol. 26, 1970, pp. 2.
[2] Y.-H. Chang and C.-Y. Chang, "A Maximum Power Point Tracking of PV System by Scaling Fuzzy Control," presented at International MultiConference of Engineers and Computer Scientists, Hong Kong, 2010.
[3] S.Mekhilef, "Performance of grid connected inverter with maximum power point tracker and power factor control," *International Journal of Power Electronics*, vol. 1, pp. 49-62, 2008.
[4] M.E.Ahmad and S.Mekhilef, "Design and Implementation of a Multi Level Three-Phase Inverter with Less Switches and Low Output Voltage Distortation," *Journal of Power Electronics*, vol. 9, pp. 594-604, 2009.
[5] S. Chin, J. Gadson, and K. Nordstrom, "Maximum Power Point Tracker," Tufts University Department of Electrical Engineering and Computer Science, 2003, pp. 1-66.
[6] R. Faranda and S. Leva, "Energy Comparison of MPPT techniques for PV Systems," *WSES Transaction on Power Systems*, vol. 3, pp. 446-455, 2008.
[7] Vikrant.A.Chaudhari, "Automatic Peak Power Traker for Solar PV Modules Using dSpacer Software.," in *Maulana Azad National Institute Of Technology* vol. Degree of Master of Technology In Energy. Bhopal: Deemed University, 2005, pp. 98.
[8] T. P. Nguyen, "Solar Panel Maximum Power Point Tracker," in *Department of Computer Science & Electrical Engineering*: University of Queensland, 2001, pp. 64.
[9] B. S, Thansoe, N. A, R. G, K. A.S., and L. C. J., "The Study and Evaluation of Maximum Power Point Tracking Systems," *International Conference on Energy and Environment 2006 (ICEE 2006)*, pp. 17-22, 2006.
[10] C. S. Lee, " A Residential DC Distribution System with Photovoltaic Array Integration.," vol. Degree of Honors Baccalaureate of Science in Electrical and Electronics Engineering, 2008, pp. 38.
[11] T. Esram and P. L.Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," in *9*. Urbana.
[12] E. I and O. Rivera, "Maximum Power Point Tracking using the Optimal Duty Ratio for DC-DC Converters and Load Matching in Photovoltaic Applications," *IEEE*, pp. 987-991, 2008.
[13] G. Adamidis, P. Bakas, and A. Balouktsis, "Photovoltaic System MPPTracker Implementation using DSP engine and buck – boost DC-DC converter."
[14] M. Azab, "A New Maximum Power Point Tracking for Photovoltaic Systems," in *WASET.ORG*, vol. 34, 2008, pp. 571-574.
[15] H. Knopf, "Analysis, Simulation, And Evaluation of Maximum Power Point Tracking (MPPT) Methods for a solar power vehicle," in *Electrical and Computer Engineering*, vol. Master of Science in Electrical and Computer Engineering: Portland State University 1999, pp. 177.
[16] T.S.USTUN and S. Mekhilef, "Effects of a Static Synchronous Series Compensator (SSSC) Based on Soft Switching 48 Pulse PWM Inverter on the Power Demand from the Grid," *Journal of Power Electronics*, vol. 10, pp. 85-90, 2010.
[17] A. Oi, "Design and Simulation of Photovoltaic Water Pumping System," in *Electrical Engineering*, vol. Master of Science in Electrical Engineering. San Luis Obispo: California Polytechnic State University, 2005, pp. 113.
[18] S. Mekhilef and M. N. A. Kadir, "Voltage Control of Three-Stage Hybrid Multilevel Inverter Using Vector Transformation," *IEEE Transactions on Power Electronics*, vol. 25, pp. 2599-2606, 2010.
[19] S. Azadeh and S. Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter," *IEEE Transaction on Industrial Electronics*,vol. DOI:10.1109/TIE.2010.2048834, 2010.
[20] P. Sanchis, J. Lopez, A. Ursua, E. Gubia, and L. Marroyo, "On the Testing, Characterization, and Evaluation of PV Inverters and Dynamic MPPT Performance Under Real Varying Operating Conditions," 2007.
[21] B. S. Energy, "What is Maximum Power Point Tracking (MPPT)," vol. 2009.
[22] J. H. Lee, H. S. Bae, and B. H. Cho, "Advanced Incremental Conductance MPPT Algorithm with a Variable Step Size," 2006