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An Improved Approach of Perturb and Observe Method Over Other Maximum Power Point Tracking Methods

Sonali Surawdhaniwar, Ritesh Diwan

*Abstract- **Maximum power point trackers (MPPTs) participate in photovoltaic (PV) power systems for the reason that they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. MPPTs find and sustain action at the maximum power point, using an MPPT algorithm. Many such algorithms have been proposed. However, one particular algorithm, the perturb-and-observe (P&O) method, claimed by many in the literature to be inferior to others, continues to be by far the most widely used method in viable PV MPPTs. Part of the reason for this is that the published comparisons between methods do not include an experimental comparison between multiple algorithms with all algorithms optimized and a standardized MPPT hardware. This paper provides such a comparison. MPPT algorithm performance is quantified through the MPPT efficiency. In this work, results are obtained for three optimized algorithms. It is found that the P&O method, when properly optimized, can have MPPT efficiencies well in excess of 97%, and is highly competitive against other MPPT algorithms***

*Keywords: **Maximum Power Point Tracking, MPPT efficiency, Power Electronics***

I. INTRODUCTION

Renewable sources of energy acquire growing importance due to massive consumption and exhaustion of fossil fuel. Among several renewable energy sources, Photovoltaic arrays are used in many applications such as water pumping, battery charging, hybrid vehicles, and grid connected PV systems [1]. As known from a (Power-Voltage) curve of a solar panel, there is an optimum operating point such that the PV delivers the maximum possible power to the load. The optimum operating point changes with the solar irradiation, and cell temperature. Therefore, on line tracking of the maximum power point of a PV array is an essential part of any successful PV system. A variety of maximum power point tracking (MPPT) methods is developed. The methods vary in implementation complexity, sensed parameters, and required number of sensors, convergence speed, and cost.

The fast increase in the demand for electricity and the varying 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 search of finding the solution to the problem. The harnessing of solar energy using PV modules comes with its own tribulations that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules [2].A great deal of research has been done to develop the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been anticipated to unravel the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers. As the market is now swamped with varieties of these MPPT that are meant to look up 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 condition. Maximum Power Point Trackers (MPPTs) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. MPPTs find and maintain operation at the maximum power point, using an MPPT algorithm.

A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load [3]. 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. 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 [4]. Therefore MPPT techniques are needed to maintain the PV array's operating at its MPP. Many MPPT techniques have been proposed in the literature; example are the Perturb and Observe (P&O) methods [3, 4, 5], Incremental Conductance (IC) methods [6, 7], Fuzzy Logic Method [8], etc. In this paper two most popular of MPPT technique Perturb and Observe (P&O) methods and Incremental Conductance methods are discussed and compared.

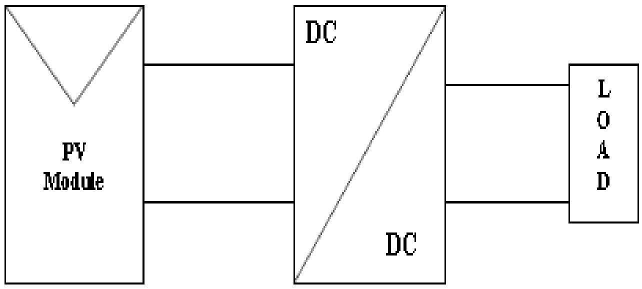

Figure1: Block diagram of Typical MPPT system

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. The equivalent electrical circuit of an ideal solar cell can be treated as a current source parallel with a diode shown in figure 2.

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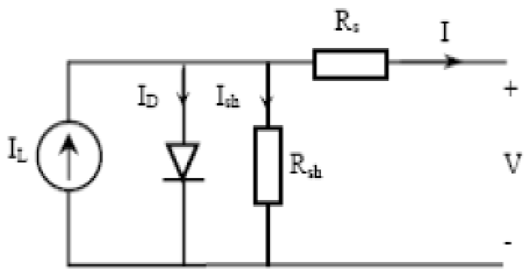

Figure2: Equivalent electrical circuit of a solar cell

The I-V characteristics of the equivalent solar cell circuit can be determined by following equations [9]. The current through diode is given by:

$ID = IO [\exp (q(V + I RS)/KT)) – 1]$ (1)

While, the solar cell output current:

$I = IL – ID – Ish$

(2)

$I = IL – IO [\exp (q(V + I RS)/KT)) – 1] – (V + IRS)/ Rsh$

(3)

Where:

I : Solar cell current (A)

I_o: 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)

R_s: Solar cell series resistance (Ω)

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

II. DC-DC CONVERTER

I. Buck Converter

The buck converter can be found in the literature as the step down converter [10]. 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 [11,12].

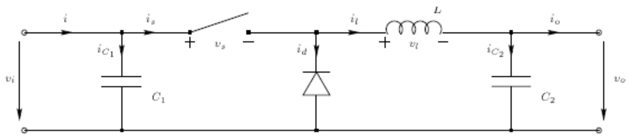

Figure3: Ideal buck converter circuit

II. 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. In [13,14] boost converter is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors in combination with inductors are normally added to the output of the converter to reduce output voltage ripple.

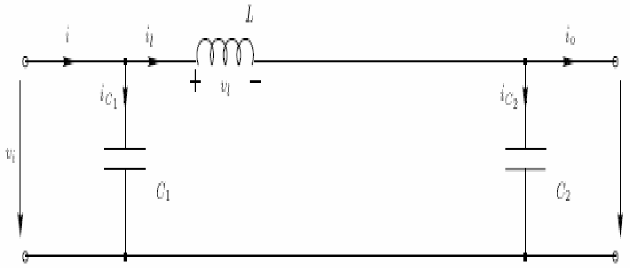

Figure4: Equivalent Circuit of a Boost Converter

III. 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 [15].

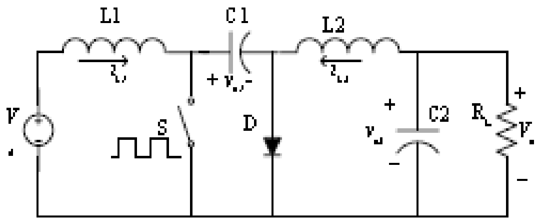

Figure5: Equivalent Circuit of Cuk Converter

III. DESCRIPTION OF MPPT ALGORITHMS

I. Perturb and Observe Method:

The Perturb and observe (P&O) algorithm is the most commonly used in practice because of its ease of implementation. The most basic form of the P&O algorithm operates as follows. Consider Figure 6, which shows a family of PV array power curves as a function of voltage (P–V curves), at different irradiance (G) levels, for uniform irradiance and constant temperature. As previously described, these curves have global maxima at the MPP. Assume the PV array to be operating at point A in Figure 7, which is far from the MPP. In the P&O algorithm, the operating voltage of the PV array is perturbed by a small increment, and the resulting change in power, ΔP, is measured. If ΔP is positive, then the perturbation of the operating voltage moved the PV arrays operating point closer to the MPP. Thus, further voltage perturbations in the same direction (that is, with the same algebraic sign) should move the operating point toward the MPP. If ΔP is negative, the system operating point has moved away from the MPP, and the algebraic sign of the perturbation should be reversed to move back toward the MPP. The advantages of this algorithm, as stated before, are simplicity and ease of implementation. However, P&O has limitations that reduce its MPPT efficiency. One such limitation is that as the amount of sunlight decreases, the P–V curve flattens out, as seen in Figure6. This makes it difficult for the MPPT to discern the location of the MPP, owing to the small change in power with respect to the perturbation of the voltage.

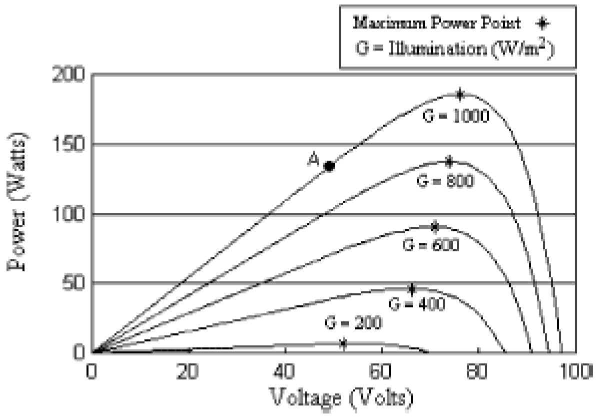

Figure6: Photovoltaic array power–voltage relationship

Another fundamental drawback of P&O is that it cannot determine when it has actually reached the MPP. Instead, it oscillates around the MPP, changing the sign of the perturbation after each ΔP measurement. Also, it has been shown that P&O can exhibit erratic behavior under rapidly changing irradiance levels. Consider the case in which the irradiance is such that it generates P–V curve 1 in Figure7. The MPPT is oscillating around the MPP from point B to A to C to A and so on. Then, assume the irradiance increases and the P–V curve of the array moves to curve 2. If, during the rapid increase in solar irradiance and output power, the MPPT was perturbing the operating point from point A to point B, the MPPT would actually move from A to D. As seen in Figure 4, this result in a positive ΔP, and the MPPT will continue perturbing in the same direction, toward point F. If the irradiance is still rapidly increasing, the PV power curve will move to G on curve 3 instead of to F on curve 2. Again the MPPT will see a positive ΔP and will assume it is moving towards the MPP, continuing to perturb to point I. From points A to D to G to I the MPPT is continually moving away from the MPP, decreasing the efficiency of the P&O algorithm. This situation can occur on partly cloudy days, when MPP tracking is most difficult, owing to the frequent movement of the MPP.

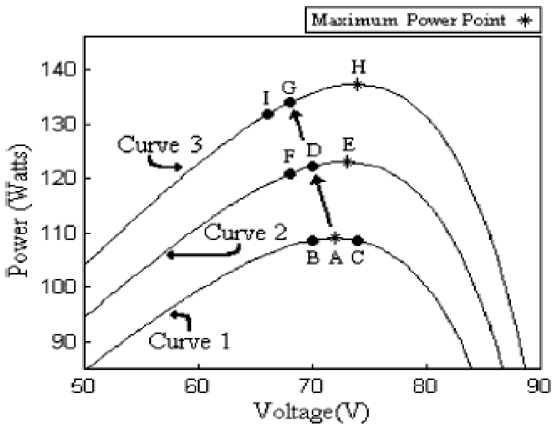

Figure7: Illustration of erratic behavior of P&O under rapidly increasing irradiance

Several improvements of the P&O algorithm have been proposed. One of the simplest entails the addition of a ‘waiting’ function that causes a momentary cessation of perturbations if the algebraic sign of the perturbation is reversed several times in a row, indicating that the MPP has been reached. This reduces the oscillation about the MPP in the steady state and improves the algorithm’s efficiency under constant irradiance conditions. However, it also makes the MPPT slower to respond to changing atmospheric conditions, worsening the erratic behavior on partly cloudy days. Another modification involves measuring the array’s power P1 at array voltage V1, perturbing the voltage and again measuring the array’s power, P2, at the new array voltage V2, and then changing the voltage back to its previous value and remeasuring the array’s power, P1, at V1. From the two measurements at V1, the algorithm can determine whether the irradiance is changing. Again, as with the previous modifications, increasing the number of samples of the array’s power slows the algorithm down. Also, it is possible to use the two measurements at V1 to make an estimate of how much the irradiance has changed between sampling periods, and to use this estimate in deciding how to perturb the operating point. This, however increases the complexity of the algorithm, and also slows the operation of the MPPT.

The P&O MPPT algorithm is mostly used, due to its ease of implementation. It is based on the following criterion: if the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further perturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed. This paper presents a simple MPPT algorithm which can be easily implemented and adopted for low cost PV applications.

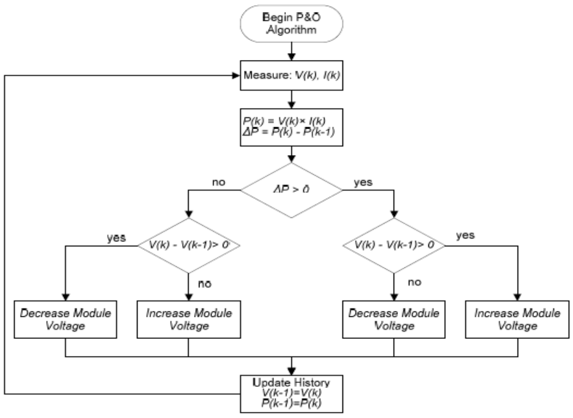

Figure8: Perturb and Observe Algorithm

[5,15]The P&O tracking method is very easy for digital control implementation. But the array voltage is perturbed every control cycle based on this method. Therefore, the P&O algorithm will oscillate around the optimal voltage when the maximum power operating point is reached.

II. 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 [6,7]. 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 dl/dV and –I/V [6].

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 [3,6] . One disadvantage of this algorithm is the increased complexity when compared to P&O.

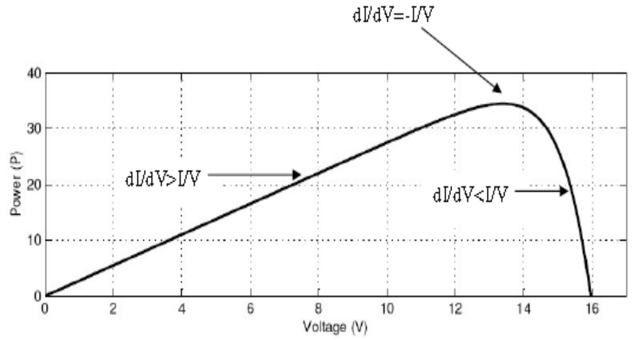

Figure9 (a): Graph Power versus Voltage for IC Algorithm

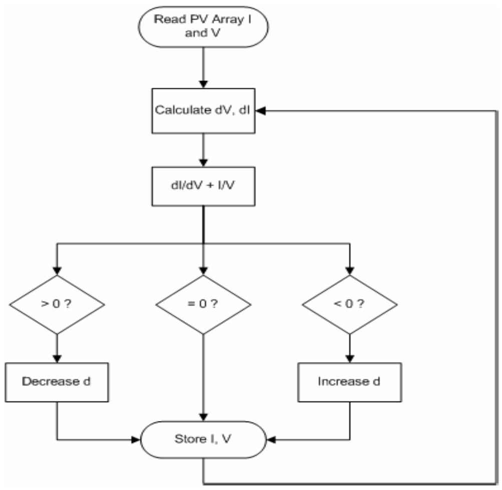

Figure9 (b): IC Algorithm

The incremental conductance algorithm is derived by differentiating the PV array power with respect to voltage and setting the result equal to zero. This is shown in Equation (4).

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV} = 0 \text{ at the MPP}$$
(4)

Rearranging Equation (4) gives

$$-\frac{I}{V} = \frac{dI}{dV}$$
(5)

Note that the left-hand side of Equation (5) represents the opposite of the PV array's instantaneous conductance, while the right-hand side represents its incremental conductance. Thus, at the MPP, these two quantities must be equal in magnitude, but opposite in sign. If the operating point is off of the MPP, a set of inequalities can be derived from Equation (5) that indicates whether the operating voltage is above or below the MPP voltage. These relationships6 are summarized in Equations (6a, b and c).

$$\frac{dI}{dV} = -\frac{I}{V}; \quad \left(\frac{dP}{dV} = 0\right) \qquad 6(a)$$

$$\frac{dI}{dV} > -\frac{I}{V}; \quad \left(\frac{dP}{dV} > 0\right) \qquad 6(b)$$

$$\frac{dI}{dV} < -\frac{I}{V}; \quad \left(\frac{dP}{dV} < 0\right) \qquad 6(c)$$

Equations 6(b and c) are used to determine the direction in which a perturbation must occur to move the operating point toward the MPP, and the perturbation is repeated until Equation 6(a) is satisfied. Once the MPP is reached, the MPPT continues to operate at this point until a change in current is measured. This change in current will correlate to a change in irradiance on the array. As shown in Figure6, as the irradiance on the array increases, the MPP moves to the right with respect to the array voltage. To compensate for this movement of the MPP, the MPPT must increase the array's operating voltage. The opposite is true when a decrease in irradiance is detected (via a decrease in the measured current). Figure9 (b) shows a flowchart for the incremental conductance algorithm. The present value and the previous value of the solar array voltage and current are used to calculate the values of dI and dV. If dV=0 and dI=0, then the atmospheric conditions have not changed and the MPPT is still operating at the MPP. If dV=0 and dI>0, then the amount of sunlight has increased, raising the MPP voltage. This requires the MPPT to increase the PV array operating voltage to track the MPP. Conversely, if dI<0, the amount of sunlight has decreased, lowering the MPP voltage and requiring the MPPT to decrease the PV array operating voltage. If the changes in voltage and current are not zero, the relationships in Equations6 (b,c) can be used to determine the direction in which the voltage must be changed in order to reach the MPP. If dI=dV > -I=V, then dP=dV > 0, and the PV array operating point is to the left of the MPP on the P–V curve. Thus, the PVarray voltage must be increased to reach the MPP. Similarly, if dI=dV < -I=V, then dP=dV < 0 and the PVarray operating point lies to the right of the MPP on the P–V curve, meaning that the voltage must be reduced to reach the MPP. Herein lies a primary advantage of incremental conductance over the perturb-and-observe algorithm: incremental conductance can actually calculate the direction in which to perturb the array's operating point to reach the MPP, and can determine when it has actually reached the MPP. Thus, under rapidly changing conditions, it should not track in the wrong direction, as P&O can, and it should not oscillate about the MPP once it reaches it.

III Parasitic capacitances:

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.

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.

IV 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 [17].

Methodology

Synchronous boost converter based photo voltaic (PV) energy system for portable applications is presented. The main advantage of using synchronous boost converter is to reduce the switching loss in the main MOSFET over conventional dc-dc boost converter. The switching loss is minimized by applying soft switching techniques such as zero-voltage switching (ZVS) and zero-current switching (ZCS) in the proposed converter. Thus the cost effective solution is obtained; especially in the design of heat sink in the dc-dc converter circuit. The DC power extracted from the PV energy system is synthesized and modulated through synchronous boost converter in order to suit the load requirements. The characteristic of PV array is studied under different values of temperature and solar irradiation. Further, the performance of such proposed method is analyzed and compared with other MPPT techniques discussed in above section. The whole system is studied in the MATLAB-Simulink environment.

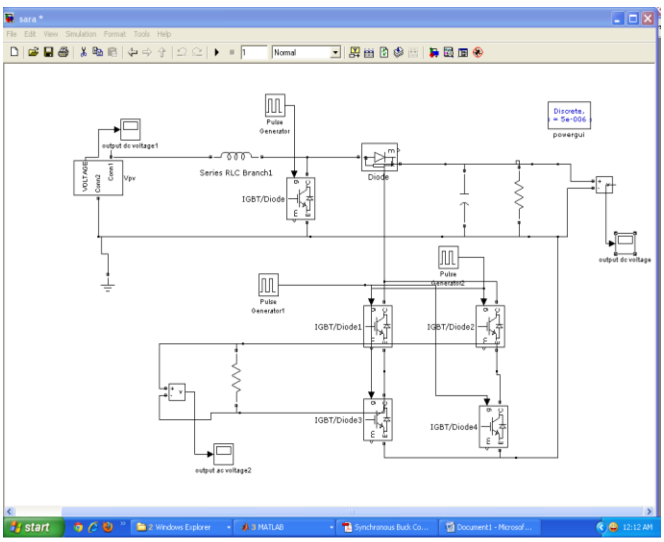

Figure10: Proposed Simulink Circuit for MPPT using P&O Method

Proposed model shown in Figure10 consists of power electronic devices such as boost converter (dc/dc converter), rectifier unit using IGBT's for generating A.C output. Solar input from the PV Module is applied at the input. Boost converter as explained in above section converts is to variable D.C voltage. Capacitor at the load end is placed to remove the ripples. Final optimized output is obtained at the output dc voltage.

Analysis and Comparison of above discussed MPPT Algorithms

The existing methods are:
1. Perturb and observe,
2. Incremental Conductance,
3. Parasitic Capacitance,
4. Voltage Based Peak Power Tracking,
5. Current Based peak power Tracking.

The first two methods, which are the most used from these five methods, are studied and compared in this paper.

Perturb and Observe Method

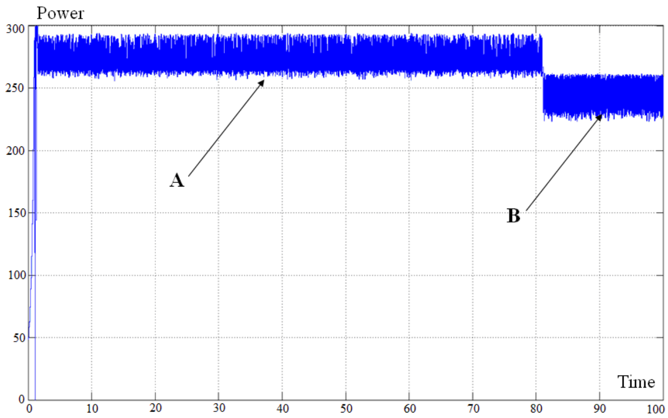

Figure11: Output power using the P&O MPPT method.

For uncertain values of temperature and sunshine, by using the 'perturb and observe' method which is already explained in the previous section, the curve of the output power versus time is presented in the Figure 11. This figure shows that the power transient state becomes very small, and this power remains constant, with small variation, in permanent state (zone A). After 80 seconds, big variations of temperature and/or sunshine followed by small ones appear in the power curve as decreasing in the average value (Zone B). In zone A and in zone B, the power ripples amplitudes are equal to 20 W. From zone A to zone B, the power decreases by 40 W.

By changing the duty cycle in the proposed method, improved values of P&O method can be obtained. The duty cycle denoted by D is to be changed by the value:

$$D= (D_n-D_{n-1})/2 \qquad (7)$$

For uncertain values of temperature and sunshine, the power waveform (figure 12) is not constant as it is shown by figure 11. But, it takes more important values.

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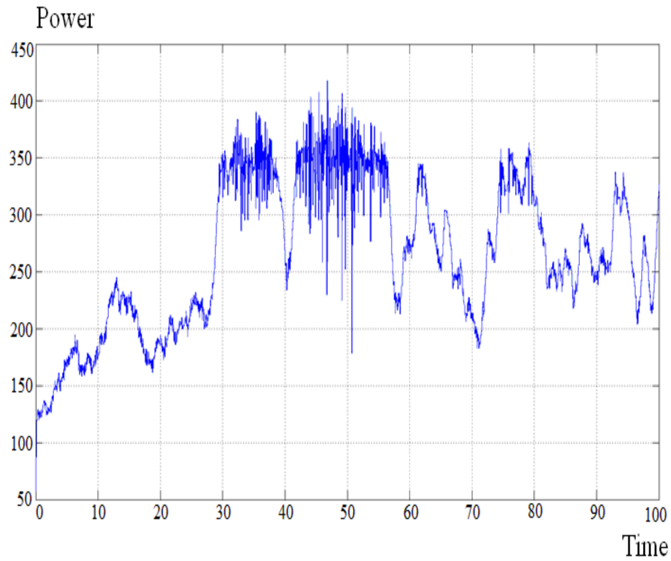

Figure12: Improved Power after changing duty cycle

Incremental Conductance Method

The temperature average value is taken equal to 25°C with variation of ±10°C applied by using the Matlab random function. With the ‘Incremental conductance’ method, the curve of the output power is illustrated in Figure13. This figure shows that the power value remains approximately constant, with small ripples.

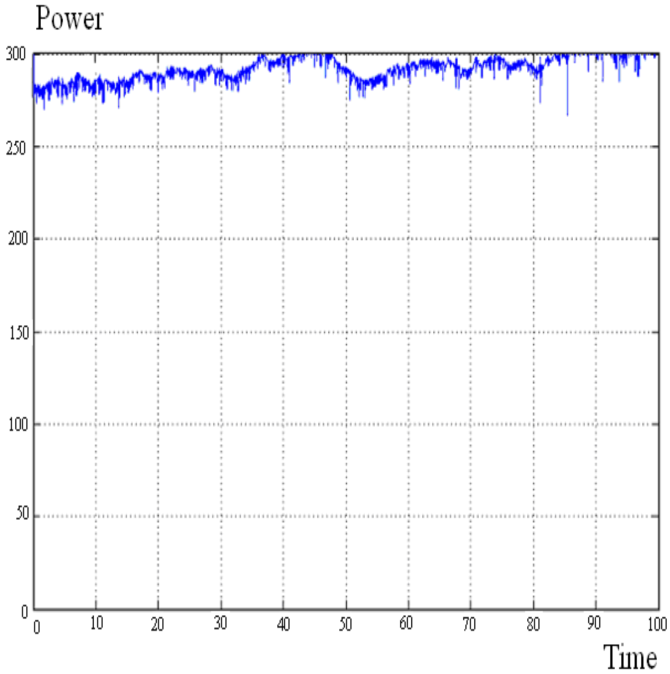

Figure13: Output power using the IC MPPT method.

To improve the studied MPPT method, it is proposed to make change on the chopper duty cycle as in case of P&O Method. The value of converter duty cycle is given as:

$$D= (D_n-D_{n-1})/2 \quad (8)$$

The improved output power after varying duty cycle is shown in Figure14.

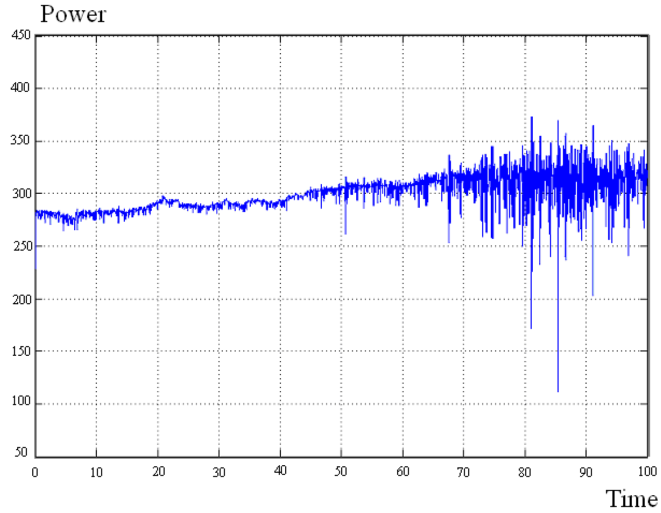

Figure14: Improved Power after changing duty cycle.

Generated power comparison for the three MPPT algorithms in the two analyzed scenarios is shown in Figure15. The incremental conductance algorithms are the ones extracting more power when an irradiance change occurs. This behavior is due to the better dynamic response of those systems, since they do not have to wait for the output of the controller to reach the steady state value. It can also be noticed that there is almost no difference between the incremental conductance algorithms, although the one using variable step is slightly better.

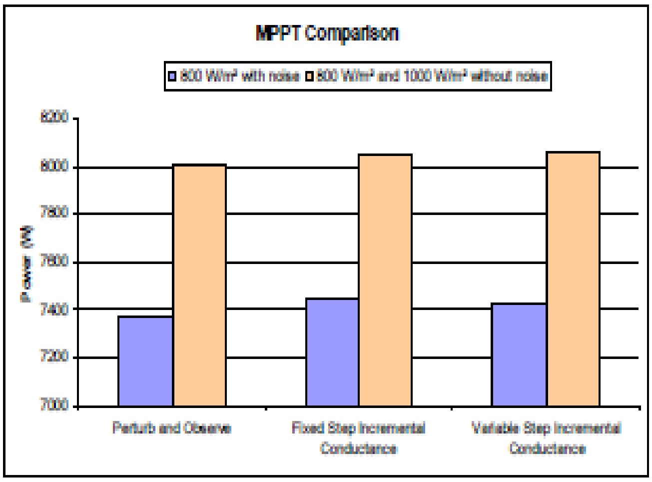

Figure15: Power comparison graph.

However, when the algorithms have to operate with noisy signals, the fixed-step incremental conductance algorithm gives a better result, due to its higher robustness, since it only needs the sign of the derivative of the generated.

Result

The temperature average value is taken equal to 25°C with variation of ±10°C applied by using the Matlab random function. For uncertain values of temperature and sunshine with small variations and by using the ‘perturb and observe’ method, the curve of the output power versus time is presented in Figure16. This figure shows that the power transient state is fast, and this power remains constant, with small variation, in permanent state.

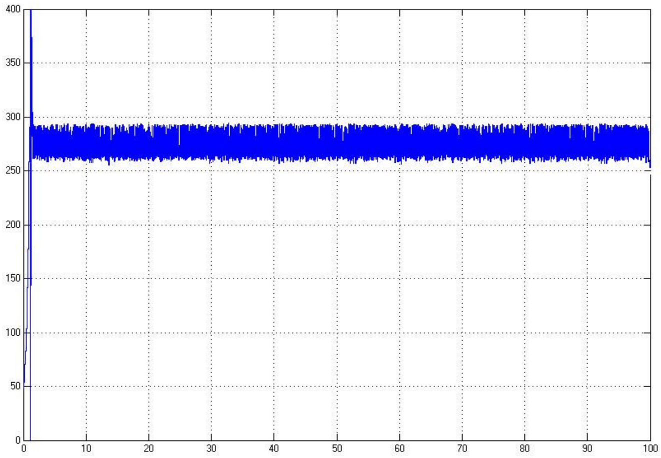

Figure16: Power versus time using the 'perturb and observe' method.

By using the 'Incremental conductance' method, the curve of the output power versus time is illustrated in Figure17.

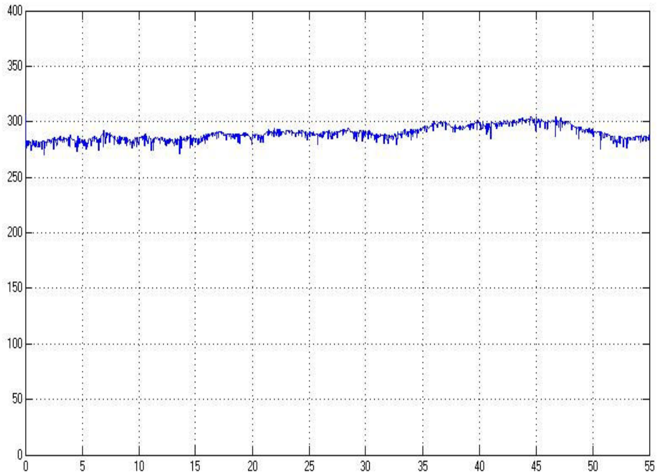

Figure17: Power versus time using the incremental conductance method.

The results suggest that the simplicity of the P&O algorithm may outweigh any advantage offered by incremental conductance in most applications, particularly low-cost applications such as module-integrated power electronics. The P&O method can be implemented with fairly simple analog circuitry or a very-low-cost microcontroller. Incremental conductance, on the other hand, requires differentiation, division circuitry and a relatively complex decision making process, and therefore requires a more complex microcontroller with more memory. The choice of which of these two MPP tracking algorithms to use in a PV system can be made by weighing the increased cost of the MPPT to the overall increase of energy produced. This would suggest that an increase in MPPT cost might be justified in a larger PV system, where a small percentage increase in efficiency would lead to a significant increase in energy output.

IV. CONCLUSION

In this paper, after presentation of the studied system, the conversion from solar energy to electrical one is treated. The 'Perturb and observe' and the 'incremental conductance' methods are used to maximize the output power. The flow chart of each method had been explained and discussed. With the incremental conductance method, compared to the perturb and observe method, simulation results underline that the time response is small, the existing ripples have low amplitude and the average power is more important. Finally, as expected, the MPPT efficiency increases gained by using the perturb-and-observe and incremental conductance algorithms make them favorable over the simpler constant voltage method.

REFERENCES

1. Robert C.N. Pilawa-Podgurski, Nathan A. Pallo, Walker R. Chan, David J. Perreault, Ivan L. Celanovic, Low-Power Maximum Power Point Tracker with Digital Control for Thermophotovoltaic Generators 978-1-4244-4783-1/10/$25.00 ©2010 IEEE.
2. Greg Smestad and Patrick Hamill, Concentration of solar radiation by white backed photovoltaic panels, APPLIED OPTICS / Vol. 23, No. 23 / 1 December 1984.
3. D. P. Hohm and M. E. Ropp,Comparative Study of Maximum Power Point Tracking Algorithms, Published online 22 November 2002 Received 12 February 2002 Copyright # 2002 John Wiley & Sons, Ltd. Revised 2 June 2002
4. Nicola Femia, *Member, IEEE*, Giovanni Petrone, Giovanni Spagnuolo, *Member*, Optimization of Perturb and Observe Maximum Power Point Tracking Method *IEEE*, and Massimo Vitelli IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 20, NO. 4, JULY 2005.
5. C. Liu, B. Wu and R. Cheung Department of Electrical & Computer Engineering, Ryerson University, Toronto, Ontario, Canada M5B 2K3, ADVANCED ALGORITHM FOR MPPT CONTROL OF PHOTOVOLTAIC SYSTEMS, *Canadian Solar Buildings Conference Montreal, August 20-24, 2004.*
6. M.Lokanadham and K.Vijaya Bhaskar, Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System, International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 2,Mar-Apr 2012, pp.1420-1424.
7. Jae Ho Lee , HyunSu Bae and Bo Hyung Cho Seoul National University School of Electrical Engineering and Computer Science, Advanced Incremental Conductance MPPTcAlgorithm with a Variable Step Size, 1-4244-0121-6/06/$20.00 ©2006 IEEE.
8. Ratna Ika Putri and M. Rifa'I Maximum Power Point Tracking Control for PhotovoltaicSystem Using Neural Fuzzy, International Journal of Computer and Electrical Engineering, Vol.4, No.1, February 2012.
9. Steven L. Brunton, Clarence W. Rowley, Sanjeev R. Kulkarni, *Fellow, IEEE*, and Charles Clarkson, Maximum Power Point Tracking for Photovoltaic Optimization Using Ripple-Based Extremum Seeking Control, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 25, NO. 10, OCTOBER 2010
10. Johan H. R. Enslin, *Senior Member, IEEE*, Mario S. Wolf, Dani¨el B. Snyman, and Wernher Swiegers, Integrated Photovoltaic Maximum Power Point Tracking Converter, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 44, NO. 6, DECEMBER 1997
11. Milan Ilic and Dragan Maksimovic, *Senior Member, IEEE*, Interleaved Zero-Current-Transition Buck Converter, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 43, NO. 6, NOVEMBER /DECEMBER 2007
12. Keyue M. Smedley, Member, IEEE, and Slobodan Cuk, Senior Member, IEEE, One-Cycle Control of Switching Converters, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 10, NO. **6,** NOVEMBER 1995
13. Tamer T.N. Khatib *National University of Malaysia, Department of Electrical Electronic & System Engineering Bangi 43600, Selangor, Malaysia*, A New Controller Scheme for Photovoltaics Power Generation Systems**,** European Journal of Scientific Research ISSN 1450-216X Vol.33 No.3 (2009),
14. pp.515-524©EuroJournalsPublishing,Inc.2009.
15. Yungtaek Jang, *Senior Member, IEEE*, Milan M. Jovanovic´, *Fellow, IEEE*, Kung-Hui Fang, and Yu-Ming Chang, High-Power-Factor Soft-Switched Boost Converter, IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 21, NO. 1, JANUARY 2006
16. Domingos S´avio Lyrio Simonetti, *Member, IEEE*, Javier Sebasti´an, *Member, IEEE*, and Javier Uceda, *Senior Member, IEEE*, The Discontinuous Conduction Mode Sepic and´ Cuk Power Factor Preregulators: Analysis and Design, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 44, NO. 5, OCTOBER 1997.

17. Dezso Sera, *Student Member, IEEE*, Remus Teodorescu, *Senior Member, IEEE*, Jochen Hantschel, and Michael Knoll, Optimized Maximum Power Point Tracker for Fast-Changing Environmental Conditions, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 55, NO. 7, JULY 2008.
18. ROBERTO FARANDA, SONIA LEVA Department of Energy Politecnico di Milano Piazza Leonardo da Vinci, 32 – 20133 Milano ITALY, Energy comparison of MPPT techniques for PV Systems, WSEAS TRANSACTIONS on POWER SYSTEMS ISSN: 1790-5060 Issue 6, Volume 3, June 2008