HILL CLIMBING TECHNIQUES FOR TRACKING MAXIMUM POWER POINT IN SOLAR PHOTOVOLTAIC SYSTEMS-A REVIEW

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Abstract- Solar Photovoltaic systems are used worldwide to utilize energy of sun for power generation during recent years. However, the available solar energy at a particular site needs to be utilized by a photovoltaic system to maximum extent for which maximum power point tracking (MPPT) techniques are used. The most commonly used techniques for MPPT, are the Hill Climbing Techniques. These include Perturb & Observe method and Incremental Conductance method to search and make the system to operate at maximum power point. Considerable research has been carried out in the Hill Climbing MPPT techniques for increasing the overall efficiency of solar PV system. In the present study, a review of Hill Climbing MPPT techniques, has been carried out with detailed flowcharts of algorithms and includes latest research papers published on MPPT techniques.

Keywords- *Solar energy, Solar Photovoltaics, MPPT, Hill Climbing Techniques, Perturb & Observe Technique, Incremental Conductance Technique.*

I. INTRODUCTION

Solar energy is a clean and renewable energy resource for power generation. The power output from a solar photovoltaic system mainly depends on the nature of the connected load because of non-linear I-V characteristics.

The PV systems connected directly to the load result in overall poor efficiency as such MPPT is to be introduced in PV systems to increase the efficiency of the system [1]. Solar radiation, load impedance and module temperature are the three factors which affect the maximum power extraction from solar PV module. I-V curve of PV module is a function of insolation and temperature which affects output current and voltage.

The increased temperature decreases the open circuit voltage (V_{oc}) while increased intensity of solar radiation increases short circuit current (I_{sc}).

Therefore I-V and P-V curve changes according to the operating conditions which alters maximum power point accordingly as shown in Fig. 1 and Fig. 2 for different irradiation and temperature respectively [2].

The concept of MPPT is to continuously monitor the terminal voltage and current and update the control signal accordingly to achieve maximum power point (MPP). A DC/DC convertor with MPPT algorithm is used between PV module and load to extract maximum available power [3].

Maximum power point tracking can be achieved by using buck chopper with positive feedback of measurement speed and algorithm for controlling - duty cycle [4-5]. By using highly efficient MPPT with the DC/DC converter to charge batteries from PV modules, the cost of PV power generation reduced by 30% [6].

A lot of research efforts have been made to achieve faster, better and accurate MPPT technique. Salas et. al., [2] classified the MPPT techniques as indirect and direct control algorithms.

The Indirect control algorithms track maximum power point using database having curves at different irradiation and temperature or simply by mathematical equations derived from different data and parameters. Direct control algorithms do not track MPP according to the database or earlier recorded parameters or simply using mathematical equations based on the already known PV characteristics, rather it uses the instant measurement of PV voltage or current to seek MPP which is independent of varying operating conditions in solar radiation, temperature and degradation of module. Berrera et. al., [7] compared the classical P&O (P&Oa), modified P&O (P&Ob), three point weight comparison (P&Oc), Constant Voltage (CV), incremental conductance (IC), open circuit voltage (OV) and short current pulse (SC) MPPT techniques by experimental test.

They suggested that modified P&O is best MPPT technique among these and preferred its implementation using microcontroller. In this paper, conventional and improvement of hill climbing MPPT techniques i.e. Perturb & Observe (P&O), Modified P&O, Incremental Conductance (INC) algorithms, are discussed.

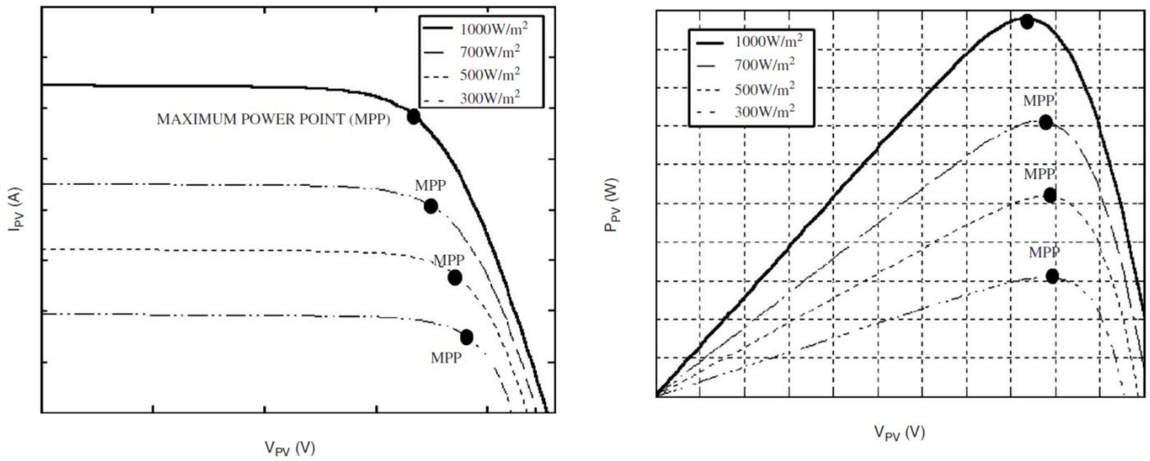

Fig.1. I-V and P-V characteristics for different irradiation level [2].

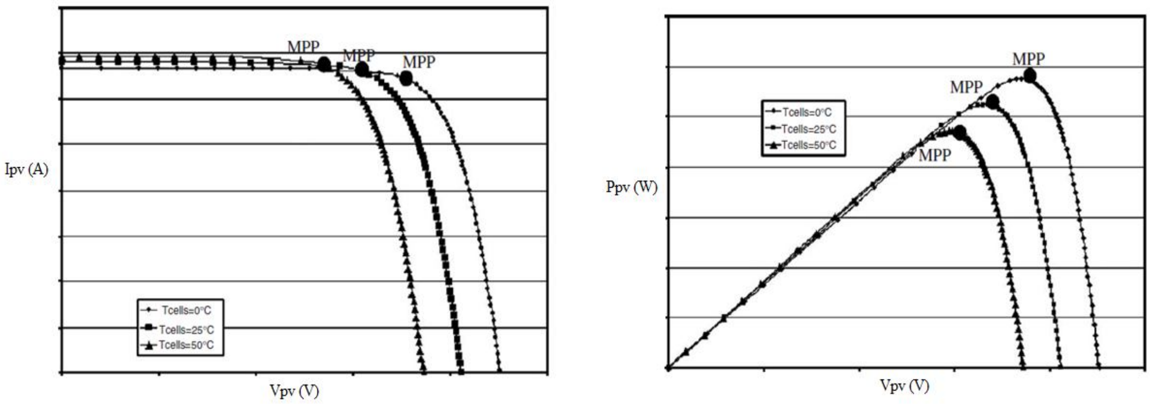

Fig. 2. I-V and P-V characteristics for different temperature level [2].

II. THE HILL CLIMBING Techniques

The hill climbing based techniques are so named because of the shape of the power-voltage (P-V) curve. This technique is sub-categorized in three types:

Perturb & Observe Algorithm (P&O)
Modified Adaptive P & O Method
Incremental Conductance Algorithm (INC)

The efficiency of P&O and INC algorithms is 96.5% and 98.2% respectively [8]. The average increase in energy extraction is found to be 16% to 43% by using conventional hill climbing MPPT [9].These algorithms are described in following sections.

A. Perturb & Observe Algorithm

The P&O algorithm is easy to implement and is most commonly used in battery charging with commercial PV modules [10]. In this method, the operating voltage or current of the PV module, is perturbed and then the power obtained is observed to decide the direction of further changes in the voltage or current. If the power is increased by the perturbation then voltage or current is kept on changing in the same direction until the power begins to fall [11]. The algorithm measures the instant voltage (V_t) and current (I_t) to calculate the power (P_t) and then compare it with last calculated power (P_{t-1}). The algorithm continuously perturbs the system if the operating point variation is positive, otherwise the direction of perturbation is changed if the operating point variation is positive. The flowchart of the algorithm is shown in Fig. 3.

P & O method can be classified in following three techniques according to the perturbation step i.e. Classic P&O, Adaptive P&O method and Three Point Weight Comparison method. Classic P&O method comprises of a fixed perturbation step. The Three Point weight comparison method selects the direction of perturb according to the result of power output at three different points on the PV curve [12].

According to the perturbing parameter, the P&O method is classified into three techniques i.e. reference voltage perturbation, reference current perturbation and duty ratio perturbation. Reference voltage perturbation P&O is fast responding with energy utilization efficiency of 97% and 97.2% for rapidly and slow varying solar radiation level respectively while the energy utilization efficiency of duty ratio perturbation P&O is 97.9 % and 99% for rapidly and slow changing irradiance level respectively [13].

The sampling frequency of the P&O algorithm is either simply increased or optimized to improve robustness of the algorithm. In optimized P&O method the perturb step size and sampling interval are optimized according to the dynamic behavior of entire system [14-15]. The perturb step size and perturb time step are optimized and calculated for efficient MPPT [16-17]. Kumar and Gupta [18] proposed an extended P&O technique, in which, MPP is converged using conventional P&O technique then the PV voltage is maintained at MPP by regulating duty cycle on the basis of difference between maximum power point voltage (V_{mpp}) and instant PV voltage (V_{pv})at regular interval.

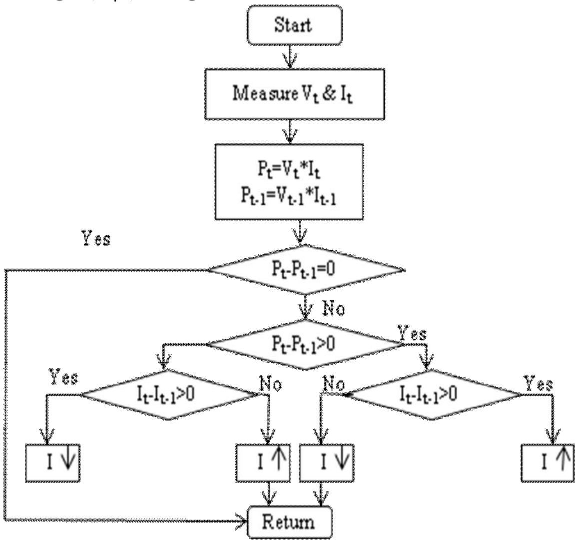

Fig. 3 Flow Chart of P&O Algorithm

B. Modified Adaptive P & O Method:

If the step size is too small, the MPPT will respond slowly in the rapidly varying operating conditions but it will give better result in stable condition. In wider step size, the MPPT will respond quickly to the frequent changes but steady state error increases. Therefore, the step size is an important parameter to decide in hill climbing MPPT techniques and it should be either optimized or we can use a bit complicated but more efficient adaptive step size hill climbing algorithms [19-20].

During cloudy weather, rapidly varying insolation confuses the hill climbing as well as adaptive hill climbing algorithm to track MPP. Moreover, constant step size of duty cycle, is also a major problem in hill climbing algorithm, small step size makes algorithm slow and large step size leads to large output power fluctuation resulting in less average output power. Therefore step size 'a' should be large during transient change of insolation while it should be small for during steady state. Therefore, two step sizes depend on a power threshold value, can be used. The small step size is used when the power difference is less than threshold value and the larger step size is applied when power difference is more than threshold value [21]. Modified adaptive P&O is best MPPT technique among all Hill Climbing techniques and its implementation is preferred using microcontroller [7].

In modified Adaptive Hill Climbing MPPT method [22], automatic tuning of step size 'a' solves the problem. The parameter 'a' is controlled by the Eq.1 The duty cycle is adjusted according to change in power (ΔP) if the value of |ΔP /a(t-1)| is greater than the threshold value e as shown in Fig. 4. If the value of |ΔP /a(t-1)| is less than e, the step size 'a' is large. The step size of the adaptive P&O technique can be updated by fuzzy logic control to decrease the decrease the oscillation [23].

$$a(t) = M\frac{|\Delta P|}{a(t-1)} \quad (1)$$

where:

$\Delta P = P(t) - P(t-1)$

M = constant parameter

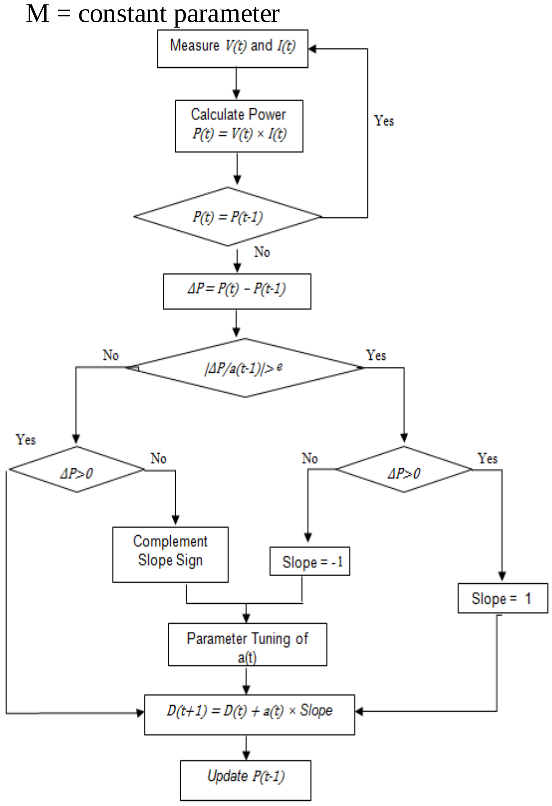

Fig. 4 Flow chart of Modified Adaptive P&O Algorithm

C. Incremental Conductance Algorithm

The incremental conductance algorithm [24] of MPPT was developed by K. H. Hussein, I. Muta, T. Hoshino and M. Osakada, however the concept technique was developed by O. Wasyneczuk [25]. They used derivative of conductance to determine the maximum power point (MPP). The MPP is determined by comparing instant conductance I/V to the incremental conductance ΔI/ΔV and the INC technique is based on the fact that slope of P-V curve is zero at MPP as shown in Fig. 5 [24]. This algorithm performs better than P&O algorithm in rapidly varying environment and is robust to the rapidly varying solar radiation [26-27]. The MPPT speed and accuracy was improved by introducing automatically adjustable variable step size to conventional INC technique [28]. When MPP is far from operating point, the step size is large for fast tracking while during operating point closer to MPP, the step size becomes small to reduce steady state oscillation.

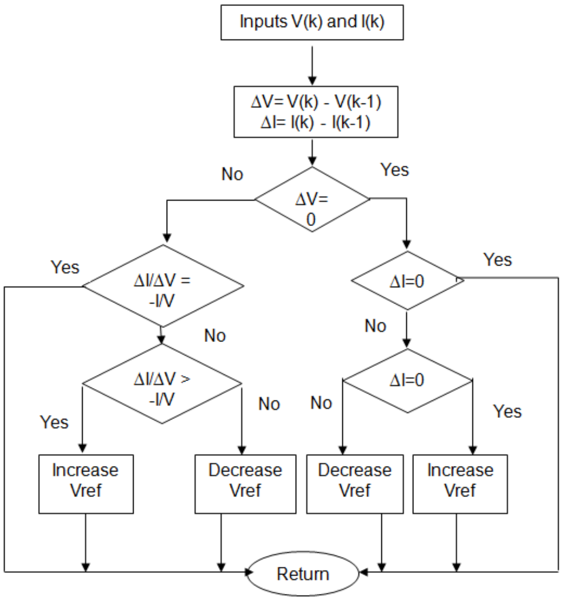

Fig. 5 Flow chart of Incremental Conductance Algorithm

The algorithm is modified and the derivative of resistance (dV/dI) is used in place of derivative of conductance [29]. The modified algorithm is variable step-size incremental resistance (INR) algorithm is based on the fact that slope of P-I curve is zero at MPP, positive on the left of MPP, and negative on the right of MPP [30].

This modification not only enhances response speed but also decreases the steady state error. The INR uses the extreme points (M1 and M2) of threshold value (C) given by eq.3 to toggle between fixed and variable step size approach. The current at these extreme points are on both sides of MPP. The INR algorithm is in fixed step size mode if the operating point is outside the extreme points. The step size is controlled by the value of threshold value at n=1(index).

$$\left.\begin{aligned}&\frac{dP}{dI} = 0, at\ MPP\\&\frac{dP}{dI} > 0, left\ of\ MPP\\&\frac{dP}{dI} < 0, right\ of\ MPP\end{aligned}\right\} \quad (2)$$

$$C = P^n \times \left|\frac{dP}{dI}\right| \quad (3)$$

Since

$$\frac{dP}{dI} = \frac{d(IV)}{dI} = V + I\frac{dV}{dI} \cong V + \frac{\Delta P}{\Delta I} \quad (4)$$

Therefore the eq. 2 can be written in incremental resistance form,

$$\left.\begin{aligned}&\frac{\Delta V}{\Delta I} = -\frac{V}{I}, at\ MPP\\&\frac{\Delta V}{\Delta I} > -\frac{V}{I}, left\ of\ MPP\\&\frac{\Delta V}{\Delta I} < -\frac{V}{I}, right\ of\ MPP\end{aligned}\right\} \quad (5)$$

III. THE ADVANCED HILL CLIMBING TECHNIQUE

The advanced hill climbing based algorithm consists of hybrid algorithm using a different algorithm technique along with the hill climbing method for faster and accurate tracking of MPP. The voltage and current controlled algorithms are more accurate and effective than most commonly used hill-climbing algorithms at low solar radiation. Therefore these algorithms are combined with P&O and INC algorithms to increase their effectiveness [12, 31-32]. The hill climbing based algorithms oscillate around the MPP in slow varying atmospheric conditions. Therefore to decrease losses due to oscillations, the hill climbing based algorithms are suitable in only rapidly changing atmospheric conditions and the constant voltage method is fast and sufficient for constant conditions. The two mode control algorithm combines these two algorithms by using incremental conductance method for more than 30% normalized solar radiation and constant voltage method for less than 30% normalized radiation [33]. The flow chart of the algorithm of this method is shown in Fig. 5.

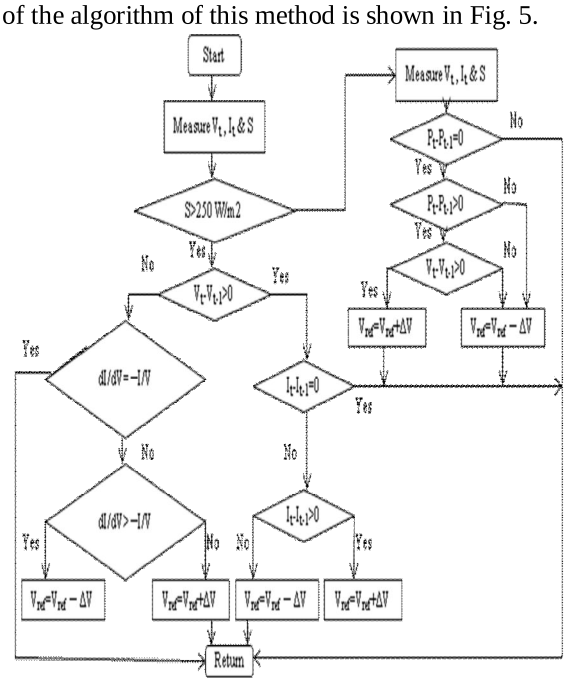

Fig. 5 Flow Chart of Two Mode Control Algorithm

IV. CONCLUSION

In the present study, a review of Hill Climbing maximum power point tracking techniques with flow charts, have been described so as to provide the latest update on conventional and advancement of HC techniques. From the study, it can be concluded that Variable step size HC techniques, both P&O and INC, are most efficient methods to track MPP.

REFERENCES

[1] M. A. El-Shibini and H. H. Rakha, "Maximum Power Point Tracking Technique", Proceedings of Electrotechnical Conference, 'Integrating Research, Industry and Education in Energy and Communication Engineering', Mediterranean 11-13 Apr 1989 pp. 21 – 24.

[2] V. Salas, E. Olias, A. Barrado and A. Lazaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems" Solar Energy Materials & Solar Cells Vol. 90, pp. 1555-1578, 2006.

[3] Henry Shu-Hung Chung, K. K. Tse, S. Y. Ron Hui, C. M. Mok, and M. T. Ho, "A Novel Maximum Power Point Tracking Technique for Solar Panels Using a SEPIC or Cuk Converter" IEEE Transactions On Power Electronics, Vol. 18, No. 3, May 2003, pp. 717-724.

[4] Eftichios Koutroulis, Kostas Kalaitzakis and Nicholas C. Voulgaris, "Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System" IEEE Transactions On Power Electronics, Vol. 16, No. 1, January 2001, pp. 46-54

[5] Jesus Gonzalez-Llorente, Eduardo I, Ortiz-Rivera and Andres Diaz, "A Maximum Power Point Tracker using Positive Feedforward Control based on the DC Motor Dynamics and PVM Mathematical Model", IEEE International Electric Machines and Drives Conference, pp. 259-264, 2009.

[6] SMM Wolf And JHR Enslin "Economical, PV Maximum Power Point Tracking Regulator with Simplistic Controller", 24th Annual IEEE Conference of Power Electronics Specialists, pp. 581 – 587, 1993.

[7] M. Berrera, A. Dolara, R. Faranda and S. Leva, "Experimental test of seven widely-adopted MPPT algorithms" 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania, pp. 1-8, 2009.

[8] D. P. Hohm, M. E. Ropp, "Comparative Study of Maximum Power Point Tracking Algorithms Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed" Conference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference, pp: 1699 – 1702, 2000.

[9] J H R Enslin, "Power Point Tracking: A Cost Saving Necessity in Solar Energy Systems" 16th Annual Conference of IEEE Industrial Electronics Society, vol.2, pp. 1073 – 1077, 1990.

[10] José Antonio Barros Vieira and Alexandre Manuel Mota, "Maximum Power Point Tracker Applied in Batteries Charging with PV Panels", IEEE International Symposium on Industrial Electronics, pp. 202-207, 2008.

[11] Mummadi Veerachary, Tomonobu Senjyu and Katsumi Uezato, "Voltage-Based Maximum Power Point Tracking Control of PV System" IEEE Transactions On Aerospace And Electronic Systems, Vol. 38, No. 1, January 2002, pp. 262-270.

[12] Roberto Faranda and Sonia Leva, "Energy comparison of MPPT techniques for PV Systems", WSEAS Transactions on Power Systems Issue 6, Vol. 3, June 2008. Pp. 446-455.

[13] Mohammed A. Elgendy, Bashar Zahawi and David J. Atkinson, "Assessment 0f P&O MPPT Algorithm Implementation Techniques for PV Pumping Applications", IEEE Transactions on Sustainable Energy, Vol. 3, No. 1, January 2012, pp. 21-33.

[14] N. Femia, G. Petrone, G. Spagnuolo and M. Vitelli, "Perturb and Observe MPPT Technique Robustness Improved", 2004 IEEE International Symposium on Industrial Electronics, Vol. 2, pp. 845-850.

[15] Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo and Massimo Vitelli, "Optimization of Perturb and Observe Maximum Power Point Tracking Method" IEEE Transactions on Power Electronics, Vol. 20, No. 4, July 2005, pp. 963-973.

[16] Ashraf Ahmed, Li Ran and Jim Bumby, "Perturbation Parameters Design for Hill Climbing MPPT Techniques" IEEE International Symposium on Industrial Electronics (ISIE), 2012, pp. 1819-1824,

[17] Hamdy Radwan and Mohamed Orabi, "The Non Ideality Effect of Optimizing the P&O MPPT Algorithm for PV Stand-Alone Applications", IEEE 34th International Telecommunications Energy Conference (INTELEC), 2012, pp. 1 – 7.

[18] Y. Shasi Kumar and Rajesh Gupta, "Maximum Power Point Tracking of Multiple Photovoltaic Arrays", Students Conference on Engineering and Systems (SCES), 2012, pp. 1-6.

[19] Dezso Sera, Remus Teodorescu, Jochen Hantschel and Michael Knoll, "Optimized Maximum Power Point Tracker for Fast Changing Environmental Conditions", IEEE Transactions on Industrial Electronics, Vol. 55 , No. 7, pp. 2629-2637.

[20] Yuncong Jiang and Jaber A. Abu Qahouq, "Evaluation of Output Current PV MPPT Controller with Different Step Sizes and Multiple Panels or Cells", Twenty-Seventh Annual IEEE Applied Power Electronics conference and Exposition (APEC), 2012, pp. 1872-1876.

[21] Yongheng Yang and Frede Blaabjerg, "A Modified P&O MPPT Algorithm for Single Phase PV Systems Based on Deadbeat Control", 6th IET International Conference on Power Electronics, Machines and Drives (PEMD), 2012, pp. 1-5.

[22] Weidong Xiao and William G. Dunford, "A Modified Adaptive Hill Climbing MPPT Method for Photovoltaic Power Systems", 35th Annual IEEE Power Electronics Specialists Conference, 2004, pp. 1957-1963.

[23] Ahmad Al Nabulsi and Rached Dhaouadi, "Efficiency Optimization of a DSP-Based Standalone PV System Using Fuzzy Logic and Dual-MPPT Control", IEEE Transactions on Industrial Informatics, Vol. 8, No. 3, August 2012, pp. 573-584.

[24] K.H. Hussein, I. Muta, T. Hoshino, M.Osakada "Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions" lEE Proc.-Gener. Transm. Distrib., Vol. 142, No.1, January 1995 pp. 59-64.

[25] O. Wasynezuk, "Dynamic Behavior of A Class Of Photovoltaic Power Systems", IEEE Transactions on Power Apparatus and Systems, Vol. 102, No. 9, September 1983, pp. 3031-3037.

[26] G.J. Kish, J.J. Lee and P.W. Lehn "Modelling and control of photovoltaic panels utilizing the incremental conductance method for maximum power point tracking" IET Renewable Power Generation, 2012, Vol. 6, No. 4, pp. 259–266.

[27] Alok Kumar Singh and R. K. Tripathi, "MPPT Scheme for Small/Large Time Partially Shaded Condition of a PV Cell, Array" 2012 Students Conference on Engineering and Systems (SCES), pp. 1-4.

[28] Fangrui Liu, Shanxu Duan, Fei Liu, Bangyin Liu, and Yong Kang, "A Variable Step Size INC MPPT Method for PV Systems" IEEE Transactions On Industrial Electronics, Vol. 55, No. 7, July 2008, pp. 2622-2628.

[29] Qiang Mei, Mingwei Shan, Liying Liu, and Josep M. Guerrero, "A Novel Improved Variable Step-Size Incremental-Resistance MPPT Method for PV Systems", IEEE transactions on industrial electronics, Vol. 58, No. 6, june 2011.

[30] Sreekanth. S and I. Jacob Raglend, "A Comparitive and Analytical Study of Various Incremental Algorithms Applied in Solar Cell", International Conference on Computing, Electronics And Electrical Technologies, pp. 452-456.

[31] Kei Irisawa, Takeshi Saito, Ichiro Takano and Yoshio Sawada, "Maximum power point tracking control of photovoltaic generation system under nonuniform insolation by means of monitoring cells", Conference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference, 2000, pp. 1707-1710.

[32] Kenji Kobayashi, Ichiro Takano, Yoshio Sawada, "A study of a two stage maximum power point tracking control of a photovoltaic system under partially shaded insolation conditions", Solar Energy Materials & Solar Cells, Vol. 90, 2006, pp. 2975-2988.

[33] G.J. Yu, Y.S. Jung, J.Y. Choi, and G.S. Kim, "A novel two-mode MPPT control algorithm based on comparative study of existing algorithms", Solar Energy, Vol. 76, 2004, pp. 455-463.