Journal of the Korean Institute of Illuminating and Electrical Installation Engineers (2013) 27(9) : 74~82
http://dx.doi.org/10.5207/JIEIE.2013.27.9.074 ISSN 1229-4691(Print) ISSN 2287-5034(Online)

A Variable Step Size Incremental Conductance MPPT of a Photovoltaic System Using DC-DC Converter with Direct Control Scheme

Jae-Hoon Cho* · Won-Pyo Hong**

Abstract

This paper presents a novel maximum power point tracking for a photovoltaic power (PV) system with a direct control plan. Maximum power point tracking (MPPT) must usually be integrated with photovoltaic (PV) power systems so that the photovoltaic arrays are able to deliver maximum available power. The maximum available power is tracked using specialized algorithms such as Perturb and Observe (P&O) and incremental Conductance (indCond) methods. The proposed method has the direct control of the MPPT algorithm to change the duty cycle of a dc-dc converter. The main difference of the proposed system to existing MPPT systems includes elimination of the proportional-integral control loop and investigation of the effect of simplifying the control circuit. The proposed method thus has not only faster dynamic performance but also high tracking accuracy. Without a conventional controller, this method can control the dc-dc converter. A simulation model and the direct control of MPPT algorithm for the PV power system are developed by Matlab/Simulink, SimPowerSystems and Matlab/Stateflow.

Key Words : Photovoltaic(PV), Maximum Power Point Tracking(MPPT), Direct Control Scheme, Matlab/Simulink and SimPowerSystems, Matlab/Stateflow, Fuzzy Membership

1. Introduction

Ever increasing energy consumption, the soaring costs and exhaustible nature of fossil fuel, and worsening global environmental issues highlight renewable energy sources as promising solutions to power issues. Solar energy has experienced remarkably rapid growth in past ten years because it is a pollution-free source of power. The power generated by a PV system is highly dependent on

* Main author : Smart Logistics Technology Institute, Hankyong National University, Korea
** Corresponding author : Dept. of Building Science & Plant Engineering, Hanbat National University, Korea
Tel : 042-821-1179, Fax : 042-821-1175
E-mail : wphong@hanbat.ac.kr
Date of submit : 2013. 6. 13
First assessment : 2013. 6. 22
Completion of assessment : 2013. 7. 24

weather conditions. For example, during cloudy periods and at night, a PV system would not generate any power. In addition, it is difficult to store the power generated by a PV system for future use. To overcome this problem, a PV system can be integrated with other alternate power sources and/or storage systems [1-3]. The combination of UC bank and battery is an attractive choice due to its high efficiency. On the other hand, a PV system requires maximum power point tracking to utilize the PV system efficiently. Many maximum power point tracking techniques have been proposed in the literature, such as perturb and observe [4, 5], incremental conductance [4, 6], and intelligent-based methods [7-9]. These methods vary in their simplicity, convergence speed and hardware implementation [10].

The Perturb and Observe (P&O) algorithm, also known as the “hill climbing” method, is widely used and the most commonly used in practice because of the simplicity of its algorithm. There are some limitations, however, in that it cannot exactly determine the Maximum Power Point (MPP) when it actually reaches the MPP and oscillates operation around the MPP. Oscillation is minimized by reducing the perturbation step size. A smaller perturbation size, however, slows tracking speed. A solution to this conflicting situation is to have a variable perturbation size that forms the suitable step size for the MPP [11].

The conventional incremental conductance MPPT (INC MPPT) algorithm that tracks the maximum power point quickly under rapidly changing atmospheric conditions uses a fixed iteration step size. A large step size contributes to faster dynamics of the power drawn from the PV array, but also to excessive steady state oscillations in voltage, current and power. A small step size reduces oscillation but causes slower dynamics in the power drawn.

To solve this problem, a modified incremental conductance algorithm with a variable step size that is automatically tuned according to the operating point is proposed [12], and a scaling factor for adjusting the step size is adopted for improving the MPPT. In most MPPT methods with variable step size, it is difficult to determine the scaling factor, which is tuned at design time to adjust step size [13].

Fuzzy logic controllers for MPPT are proposed to resolve the drawbacks of the conventional methods. The fuzzy logic controllers have the advantages of working with imprecise input, not needing an accurate mathematical model, and handling nonlinearity. It generally consists of three stages such as fuzzification, rule base table lookup and defuzzification. Experimental results [14] show rapid convergence to the MPP and minimal fluctuation. However, since the output characteristics of a PV system should be solidly ascertained to create the MPPT control rule and complexity for implementation, the tracking performance of these methods is limited. A PI controller can be used in general MPPT algorithms, but requires a control loop for regulating the current of MPP calculated by the MPPT algorithm. For a simple control loop, a direct control MPPT is proposed [15]. The direct control of the MPPT is simpler and uses only one control loop where the PI controller is excepted because it performs the adjustment of the duty cycle within the MPPT algorithm. The aim of this paper is to design an MPPT with improved dynamic performance and a simple structure for faster convergence. Therefore, a variable step size incremental conductance direct MPPT method using a fuzzy membership for a standalone photovoltaic (PV) system is proposed in this paper. This method adopts a fuzzy membership function for the dynamic performance under quickly changing irradiation and the direct control for the simplicity in the algorithm. A simulation model for the PV power system is developed and performed with Matlab/Simulink, SimPowerSystems and Matlab/Stateflow [16]. The results of the proposed method appear to be more effective than conventional methods in transient conditions.

2. PV Array and Maximum Power Tracking

2.1 PV array system

A PV array consists of many cells connected in series and parallel to provide a desired output voltage. Usually, the PV system exhibits a nonlinear I-V characteristic, and PV equations for modeling the characteristic have been developed. A verified model for silicon solar PV cell has been introduced in [17]. Recently, detailed models including nonlinear effects such as resistive losses, non-ohmic-current and temperature have been developed for more accurate modeling.

a ideality or completion factor
I_0 PV cell reverse saturation current [A]
I_{PV} PV cell output current [A]
I_{sc} short-circuit cell current (representing irradiation level [A])
k Boltzmann's constant [J/K]
N_p the number of parallel strings
N_s the number of series cells per string
q electron charge [C]
R_s series resistance of PV cell [U]
T_{PV} cell temperature [K]
V_{OC} open-circuit voltage [V]
V_{PV} terminal voltage for PV cell [V]

A simple equation model, which represents the dynamic nonlinear I-V characteristics of the PV array, is modified and can be used for analyzing the effects among components of the hybrid system. The parameters used in the mathematical modeling of the PV cells are as follows: The output voltage characteristic of the PV system may be expressed as [18]:

$$V_{PV} = \frac{N_s \alpha k T}{q} \ln\left[\frac{I_{sc} - I_{PV} + N_p}{N_p I_0}\right] - \frac{N_s}{N_p} R_s I_{PV} \quad (1)$$

The manufacturer's datasheet provides necessary information for most of the parameters of Eq. (1) [18]. The current-voltage characteristics of the PV array can be obtained and analyzed by using Eq. (1). Using the current voltage curves, the current-power curves can be obtained to operate with maximum efficiency and produce a maximum output power. The maximum power output of the PV array varies according to solar radiation or temperature. Therefore, an MPPT is needed to maintain the solar array more effectively as an electric power source [19]. In this paper, the PV array model with a 2D-Lookup table and a controlled current source is used for simulation time and computational efficiency[17]. The irradiance data and the I-V characteristic curve of PV array can be used for modeling the PV output power. Fig. 1 shows a PV array Matlab/Simulink model using the 2D-Lookup table and the controlled current source. The input data for 2D Look-up table are irradiance data and output voltage of the PV array.

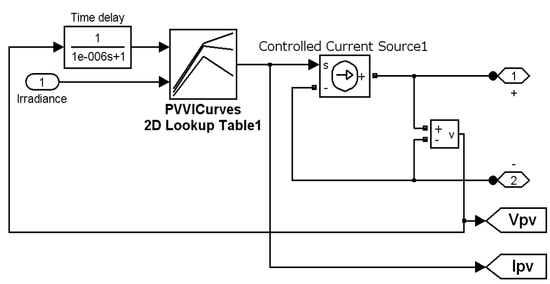


Fig. 1. Matlab/Simulink model for PV array

Table 1. Parameters of the PV array

PV system Parameters	Values
The number of series cells per string	105
The number of parallel cells per strings	148
Ideality or completion factor	1.9
Boltzmann's constant	1.3805e23J/K
PV cell temperature	298K
Electron charge	1.6e-19 C
Short-circuit cell current (A)	2.926
PV cell reverse saturation current (A)	0.00005
Series resistance of PV cell (Ω)	0.0277

2.2 Incremental Conductance Method

The flowchart shown in Fig. 2 explains the operation of this algorithm. It starts with measuring the present values of the PV array voltage and current. Then, it calculates the incremental changes, dI and dV, using the present values and previous values of voltage and current.

$$dP/dV = 0, \text{ at MPP}$$
$$dP/dV > 0, \text{ left of MPP}$$
$$dP/dV < 0, \text{ right of MPP} \quad (2)$$

Since Eq. (2) can be rewritten as

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \simeq I + V\frac{\Delta I}{\Delta V} \quad (3)$$

$$\Delta I/\Delta V = -I/V, \text{ at MPP}$$
$$\Delta I/\Delta V > -I/V, \text{ left of MPP}$$
$$\Delta I/\Delta V < -I/V, \text{ right of MPP} \quad (4)$$

If the condition satisfies $\Delta I/\Delta V > -I/V$, then the operating point is at the left side of the MPP. Thus, MPP must be moved to the right by increasing the module voltage. Similarly, if the condition satisfies $\Delta I/\Delta V > -I/V$, it is considered that the operating point is at the right side of the MPP. Thus, MPP must be moved to the left by decreasing the array voltage[13].

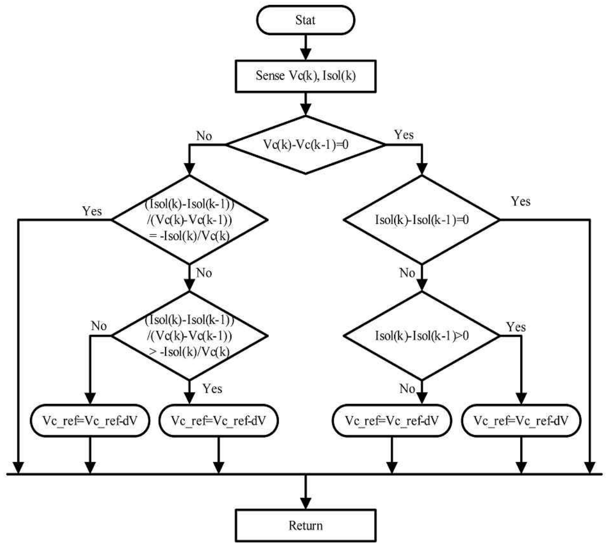


Fig. 2. Flowchart of the incremental conductance algorithm

3. Incremental Conductance Direct MPPT Method

Comparative studies [11,19,20] show that an incremental conductance method tracks faster the maximum power point under rapidly changing atmospheric conditions.

Conventional INC MPPT algorithms have two independent control loops to control the MPPT. The first control loop contains the MPPT algorithm, and the second one is usually a proportional (P) or P-integral (PI) controller. The INC MPPT method makes use of instantaneous and INC MPPT to generate an error signal, which is zero at the MPP. However, it is not zero at most of the operating points. The main purpose of the second control loop is to decrease the error from MPPs to close to zero. However, the MPPT system of standalone PV is a nonlinear control problem due to the nonlinearity nature of PV and unpredictable environmental conditions, and hence, PI controllers do not generally work well [21]. On the other hand, compared with the general MPPT algorithms, the direct control of the MPPT algorithm is simpler and uses only one control loop as shown in Fig. 3 and Fig. 4. The PI controller of the MPPT is excepted because it directly performs the adjustment of the duty cycle within the MPPT algorithm. However, the direct INC MPPT has some drawbacks under the rapidly changing irradiation of a PV system because it uses a fixed iteration step size [22].

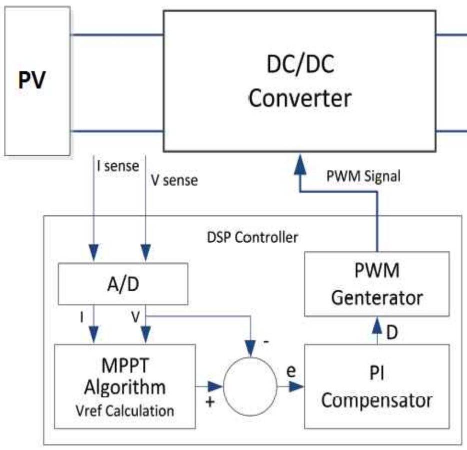


Fig. 3. Block diagram of MPPT with the PI controller

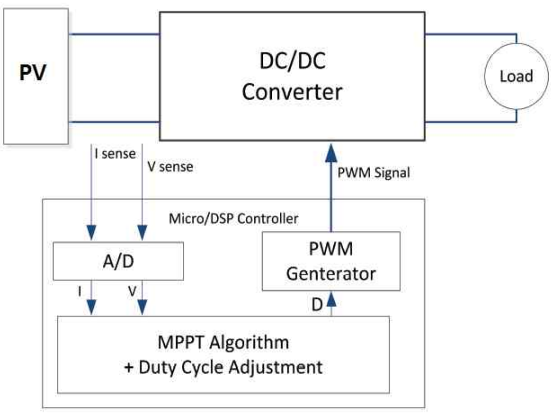


Fig. 4. Block diagram of MPPT with the direct control

4. The Proposed Method for Variable Step Size INC MPPT

The step size of the INC MPPT method is generally fixed. The power drawn from the PV array with a lager step size contributes to faster dynamics. However, this operation causes excessive steady state oscillations and comparatively low efficiency. This situation is reversed while the MPPT is running with a smaller step size. Thus, the MPPT with fixed step size should make a satisfactory tradeoff between the dynamics and oscillations. Such design problems can be solved with variable step size iteration [23, 24]. Some variable step size methods have been proposed for P&O based hill climbing MPPT and the derivation of the essential parameters of variable step size has been also provided [13]. In [13], a modified variable step size INCMPPT method and a simple process for determining the initial parameter were proposed. The update rule of this method was adopted to improve tracking accuracy as well as tracking dynamics. The update rule was shown as follows:

$$D(k) = D(k-1) \pm N\left|\frac{P(k)-P(k-1)}{V(k)-V(k-1)}\right| \tag{5}$$

where coefficient N is the scaling factor for the step size of the duty cycle in direct control. *V(k)* and *P(k)* are the PV system output voltage and current at time k and *D(k)* is the step size of the duty cycle. Scaling factor N essentially influences the performance of the INC MPPT system. Manual tuning of this parameter is incorrect and the obtained results may be valid only for a given system and operating condition [24]. Therefore, a simple method to determine the scaling factor was proposed in [13].

$$N < \triangle D_{\max} / \left| \frac{dP}{dV} \right|_{fixed\, srep = \triangle Dmax} \quad (6)$$

where $\triangle Dmax$ is the maximum step-change in duty cycle in the previous sampling period. The results showed that it has a faster dynamic performance and lower oscillation than conventional methods. However, the simulation of this update rule is only performed and tested over the short-term with a simple profile of irradiation. In this paper, a fuzzy membership based variable step direct incremental conductance algorithm having a new scaling factor N_p is proposed. For good performance and tracking accuracy under rapidly changing, short-term irradiation, the scaling factor N_p is initially considered and determined by the maximum irradiation value and the maximum variation of irradiation among all samples, and then the step size of this method *D(k)step size* is evaluated by

$$D(k)_{step\_size} = N_p \left[1 - \frac{1}{1 + \exp[-a(\Delta p - c)]} \right] \quad (7)$$

where parameter a controls the slope at the crossover point *c*. Fig. 5 shows a membership function for evaluating the variable duty cycle. By using the function, improved tracking performance and faster convergence to MPP is obtained due to smoothly changing values of the sigmoid function. The flowchart of the proposed method is indicated in Fig. 6. As shown in Fig. 6, the current and voltage of the PV array is acquired, and then the step size *D(k)step size* is evaluated by Eq. (7). Since it is similar to the conventional direct INC MPPT of the process for selecting the step size, the proposed method has not only adequate tracking accuracy but also a simple structure for the tracking speed.

In this paper, direct control of the MPPT algorithm is adopted for changing the duty cycle of a dc-dc converter. A PI controller can be used in general MPPT algorithms, but requires a control loop for regulating the current of the MPP calculated by the MPPT algorithm. Compared to the general MPPT algorithms, the direct control of the MPPT algorithm shown in Fig. 7 is simpler and uses only one control loop in which the PI controller is excepted because it performs the adjustment of the duty cycle within the MPPT algorithm as shown in Fig. 7.

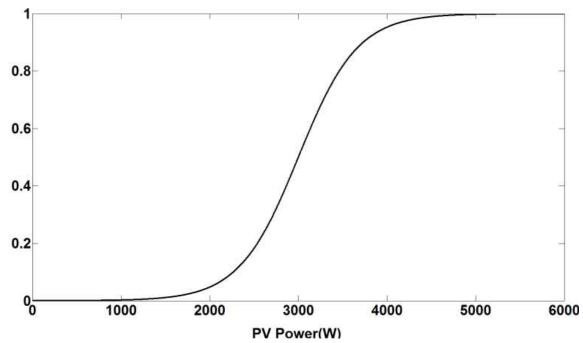


Fig. 5. Membership function for evaluating the variable duty cycle

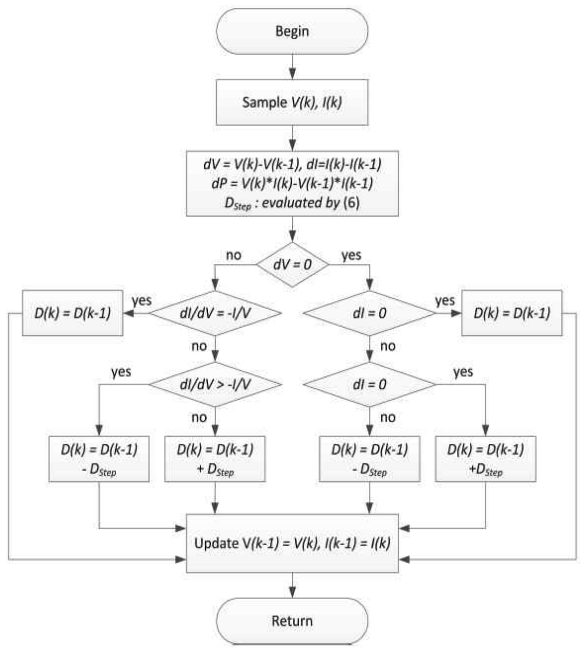


Fig. 6. Flowchart of the proposed method

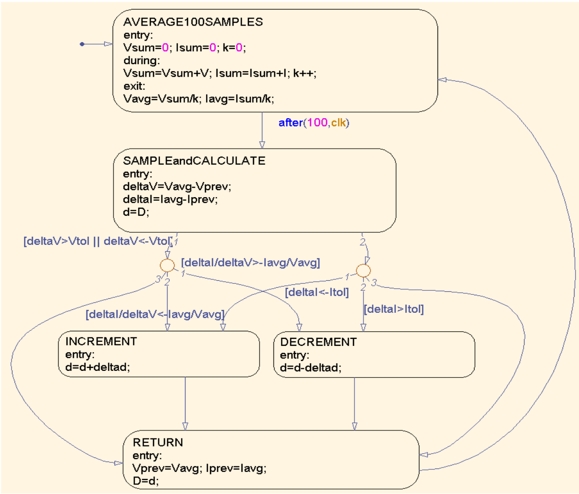


Fig. 7. Matlab/Stateflow chart of the proposed method

5. Simulation results and analysis

In order to verify the performance of the proposed MPPT method, the block diagram of the PV system including the MPPT block and dc-dc converter are designed as shown in Fig. 8. In the simulation process, the aim is to observe the proposed MPPT behavior over a short period of time including highly variable irradiation.

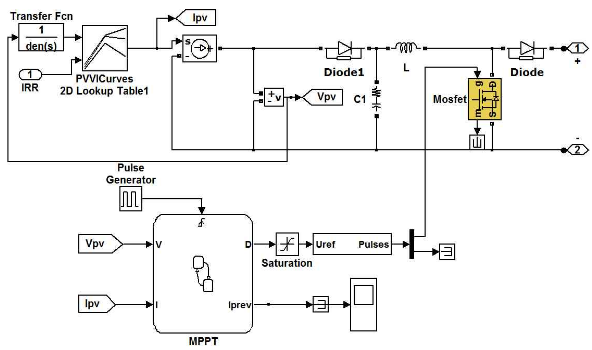


Fig. 8. The direct control model of PV system with dc-dc converter

Thus, the solar irradiation profile as shown in Fig. 9 is used for this simulation. The irradiance is changed from about $20W/m^2$ to $700W/m^2$ for 1 second. To avoid the oscillation around the MPP, the parameters of Eq. (7) are set as a = 0.05 and c = 150, respectively. Also, the scale factor of N_p = 0.02 was chosen from the above mentioned maximum irradiation value to obtain lower oscillation without losing tracking performance. To compare the performance of the proposed method with the conventional INC MPPT, N is set as 0.05 for Eq. (6) and all simulations are performed with the same irradiation.

Fig. 10 shows the output power of a PV system with each MPPT algorithm corresponding to the irradiation.

For the wide fluctuation range of the irradiation, which is from 0.3 to 0.5 as shown in Fig. 9, the proposed method shows higher performance than other methods. In the small fluctuation range after 0.6 sec, although compared to other methods, the power of the proposed method has the same or poor performance, the average power in this range is higher than others. As shown in Fig. 10, the proposed method appears to be more effective than previous methods under transient conditions. In PV output power efficiency, the average output power of the proposed method increases by about 30% and 40% compared to previous methods, respectively.

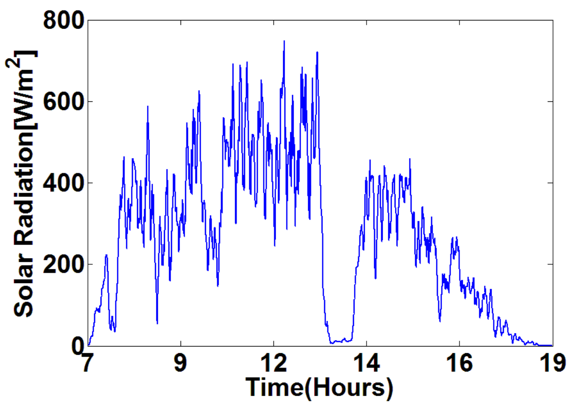


Fig. 9. Solar radiation for simulation

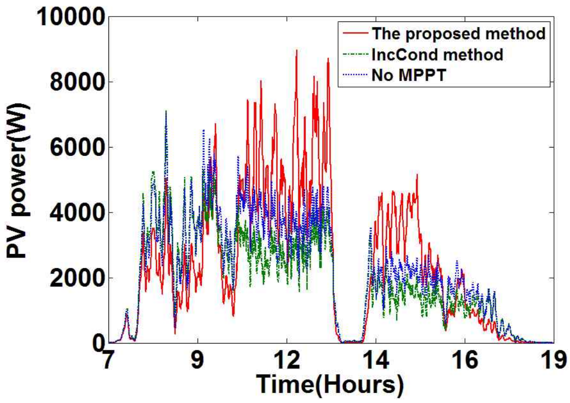


Fig. 10. Output power of PV system by MPPT algorithms

6. Conclusion

In this paper, a novel maximum power point tracking for photovoltaic power (PV) systems with direct control scheme is proposed. The available power from the PV energy source is highly dependent on environmental conditions. To overcome this deficiency of the PV technology, direct control of the MPPT algorithm is adopted for changing the duty cycle of the dc-dc converter. A detailed simulation model has been developed to allow designing and analyzing any PV/UC/battery system with various power levels and parameters. The dynamic performances of the hybrid system is tested under varying solar radiation and load demand conditions where the solar radiation and power demand data are based on real-world records.

The proposed method was tested under varying solar radiation conditions and appears to be more effective than previous methods in transient conditions.

References

[1] Kyoungsoo R, Rahman S. Two-loop controller for maximizing performance of a grid-connected photovoltaic-fuel cell hybrid power plant. IEEE Transactions Energy Conversion 1998;13(3), pp.276 - 281.

[2] El-Shatter TF, Eskandar MN, El-Hagry MT. Hybrid PV/fuel cell system design and simulation. Renewable Energy 2002;27(3), pp.479 - 485.

[3] Gorgun H. Dynamic modeling of a proton exchange membrane (PEM) electrolyzer. International Journal of Hydrogen Energy 2006;31(1):29 - 38.

[4] 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 and Solar Cells, Vol.90, Issue 11, pp. 1555-1578, 2006.

[5] A. Mellit, H. Rezzouk, A. Messai, and B. Medjahed, "PGA-based real time implementation of MPPT controller for photovoltaic systems," Renewable Energy, Vol.36, Issue 5, pp. 1652-1661, 2011.

[6] G. Li and H. A. Wang, "Novel stand-alone PV generation system based on variable step size INC MPPT and SVPWM control," IEEE 6th Int. Power Electronics and Motion Control Conf., IEEEIPEMC' 09, pp. 2155-2160, 2009.

[7] Syafaruddin, E. Karatepe, and T. Hiyama, "Polar coordinated fuzzy controller based real-time maximum-power point control of photovoltaic system," Renewable Energy, Vol.34, Issue 12, pp. 2597-2606, 2009.

[8] A. Messai, A. Mellit, A. Guessoum, and S. A. Kalogirou, "Maximum power point tracking using a GA optimized fuzzy logic controller and its FPGA implementation," Solar Energy, Vol.85, Issue 2, pp. 265-277, 2011.

[9] A.Mellit and S. A. Kalogirou, "Artificial intelligence techniques for photovoltaic applications: a review," Progress in Energy and Combustion Science, Vol.34, Issue 5, pp. 574-632, 2008.

[10] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," IEEE Trans. Energy Convers., Vol.22, No.2, pp. 439-449, 2007.

[11] A. Pandey, N. Dasgupta, and A. K. Mukerjee, "Design issues in implementing MPPT for improved tracking and dynamic performance," in Proc. IEEE IECON 2006, pp. 4387-4391, 2006.

[12] F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, "A variable step size INCMPPT method for PV systems," IEEE Trans. Ind. Electron., Vol.55, No.7, pp. 2622-2628, 2008.

[13] T. Senjyu and K. Uezato, "Maximum power point tracker using fuzzy control for photovoltaic arrays," in Proc. IEEE Int. Conf. Ind. Technol., pp. 143-147, 1994.

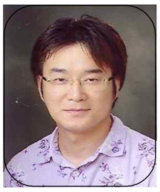
[14] M. Uzunoglu, Onar O.C, Alam M.S. Modeling, control and simulation of a PV/FC/UC based hybrid power generation system for stand-alone application. Renewable Energy 32(2009), pp. 509-520.

[15] Azadeh Safari and Saad Mekhilef, Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 58, NO. 4, APRIL 2011.

[16] MATLAB SimPowerSystems for use with Simulink user's guide, version .1.1.http://www.mathworks.com/access/helpdesk

/help/pdf__doc/physmod/powersys/powersys.pdf.
[17] M. Veerachary, T. Senjyu, and K. Uezato, "Voltage-based maximum power point tracking control of PV system," IEEE Transactions on Aerospace and Electronic Systems, Vol.38, Issue 1, pp. 262-270, 2002.
[18] Y. Sukamongkol, S. Chungpaibulpatana, and W. Ongsakul, "A simulation model for predicting the performance of a solar photovoltaic system with alternating current loads," Renewable Energy, Vol.27, Issue 2, pp.237-258, 2002.
[19] K. H. Hussein, I. Muta, T. Hoshino, and M. Osakada, "Maximum Photovoltaic Power Tracking : an Algorithm for Rapidly Changing atmospheric Conditions," IEE Proceedings-Generation, Transmission and Distribution, Vol.142, pp. 59-64, 1995.
[20] I. Houssamo, F. Locment, and M. Sechilario, "Maximum power tracking for photovoltaic power system: development and experimental comparison of two algorithms," Renewable Energy, Vol.35, Issue 10, pp. 2381-2387, 2010.
[21] F. Salem, M. S. A. Moteleb, and H. T. Dorrah, An enhanced fuzzy-PI controller applied to the MPPT problem," J. Sci. Eng., Vol.8, No.2, pp. 147-153, 2005.
[22] L. Yang, J. Cao, and Z. Li, "Principles and implementation of maximum power point tracking in photovoltaic system," International Conference on Mechanic Automation and Control Engineering (MACE), pp. 2239-2242, 2010.
[23] K. Noppadol, W. Theerayod, and S. Phaophak, "FPGA implementation of MPPT using variable step-size P&O algorithm for PV applications," in Proc. ISCIT, pp. 212-215, 2006.
[24] A. Pandey, N. Dasgupta, and A. K. Mukerjee, "Design issues in implementing MPPT for improved tracking and dynamic performance,"in Proc. IEEE IECON, pp. 4387-4391, 2006.

Biography



Jae-Hoon Cho

Jae-Hoon Cho received an M.S. degree in Control and Instrumentation Engineering from Hanbat National University, Korea in 2002. He received a Ph.D. degree in Electrical and Computer Engineering at Chungbuk National University, Korea in 2011. He is a research professor for the Smart Logistics Technology Institute, Hankyong National University. His interests are evolutionary computation, swarm intelligence, pattern recognition, neural network, power management system for smart grid and bioinformatics.

Won-Pyo Hong

Won-Pyo Hong received a B.S. degree in Electrical Engineering from Sungsil University, Seoul, Korea, in 1978 and M.Sc. and Ph.D. degrees in Electrical Engineering from Seoul National University, Seoul, Korea, in 1980 and 1989, respectively. From 1980 to 1993, he was senior researcher of the Korea Electric Power Research Institute at the Korea Electric Power Cooperation. He was visiting professor at the UBC, Canada, from 2007 to 2008. He is a professor in the Department of Building Services and Plant Engineering of Hanbat National University, where he has taught since 1993. His main research interests are building energy and management systems, smart green buildings, fieldbus bus-based control and distributed energy resources.