GLOBAL JOURNAL OF ENGINEERING, DESIGN & TECHNOLOGY
(Published By: Global Institute for Research & Education)
www.gifre.org

# A REVIEW OF MAXIMUM POWER POINT TRACKING ALGORITHM FOR PHOTOVOLTAIC SYSTEM

M. Abdulkadir, B U Musa, & I. A. Ali.
Department of Electrical and Electronics, Faculty of Engineering, University of Maiduguri, Borno State, Nigeria

**Abstract**— Due to world energy crisis and growing demand for energy as the conventional energy sources have become increasingly unable to meet the world demand for the energy. Especially, the energy obtained from solar arrays and the fuel cells, becomes more and more important. This paper presents the review of maximum power point tracking for photovoltaic system. The review also focuses on inverter and converter's technologies for connecting photovoltaic systems. The maximum power point tracking were analysis as past, present and future methods.

***Keywords***— Photovoltaic (PV), Maximum Power Point (MPP), Maximum Power Point Tracking (MPPT), dc-dc Converter, inverters

## I. Introduction

Photovoltaic energy system has gained wide popularity in the past decade as one of the renewable energy sources due to the possibility of depletion of conventional energy sources and its high cost as well as its negative effects on the environment. With world economic development and growing demand for energy, the conventional energy sources have become increasingly unable to meet the world demand for the energy. Thus, it is important to explore more and better means of an alternative energy sources like sunlight, wind and biomass.

Photovoltaic energy is a source of interesting energy; it is renewable, inexhaustible and non-polluting and it is more and more intensively used as energy sources in various applications. Photovoltaic energy is preferred because it is clean, and secure. Therefore, a photovoltaic energy generation system could be one of the significant sources as an alternative energy for the future. In regard to endless importance of photovoltaic energy, it is worth saying that photovoltaic energy is a unique prospective solution for energy crisis. Meanwhile, despite all these advantages of photovoltaic energy, they do not present desirable efficiency [1], [2]. The efficiency of photovoltaic cells depends on many factors such as temperature, insolation, spectral characteristics of sunlight, dust, shading which result in poor performance. The photovoltaic system has a nonlinear behaviour. The typical power-voltage and current-voltage characteristics of photovoltaic cells are as shown in Fig. 1. It has an optimum operating point to extract the maximum power called the maximum power point (MPP), which varies depending on cell temperature, insolation level, the nature of load, the technology of the photovoltaic cells [3], [4]. In addressing the poor efficiency of photovoltaic systems, in the past decades, a number of methods have been proposed to extract the maximum power of the solar cell. Among these methods, the direct approaches which are based on the use of the I-V curve features, such as the axis intercepts and the gradients at selected points, to determine some photovoltaic parameters. The accuracy of these techniques is therefore limited by the measured I-V data, whose errors are introduced by the numerical differentiation and the simplified formulas used in parameter extraction as well. Besides, several different conventional nonlinear fitting algorithms, such as the quasi-Newton method and its variations, have been proposed to solve above solar cell parameter extraction problem. Other maximum power point extraction techniques that have been proposed in recent time are the well-known perturbation and observation (P&O) which works satisfactorily when the irradiance fluctuates very slowly [5] – [10]. However, it often fails to track global maximum power point when irradiance changed suddenly. Another widely used approach is the incremental conductance [11], offers better tracking performance but oscillation around the maximum power point still occurs. Recently artificial intelligence methods which include Fuzzy logic [12] and Neural network (NN) [13] have been applied to track the maximum power point.

Most of the maximum power point extraction control algorithm mentions above operate very satisfactorily under uniform irradiance conditions in which only a single maximum power point is to be detected. If multiple MPPs exist due to the partial shading, the usefulness of the conventional MPPT algorithms diminishes rapidly. Since the maximum power point (i.e. it detects the local maximum power point instead of the global maximum power point), efficiency of the PV system reduced significantly [14, 15]. As a result, significant research has been carried out to reduce the effects by improving the maximum power point capability. Since MPPT, algorithms used in PV systems is one of the most important factors affecting the electrical efficiency of the system, this work will review an efficient algorithm which will be applied to extract the MPP of the photovoltaic system. Also, an overview of existing power converter and inverter's topologies for the photovoltaic system is given. Finally, a critical discussion is made, and a conclusion is drawn.

## Photovoltaic System Overview

Photovoltaic systems are solar energy systems that produce electricity directly from sunlight. Photovoltaic (PV) systems produce clean, reliable energy without consuming fossil fuels and can be used in a wide variety of applications. A common application of PV technology is providing power for electrical appliances. On a larger scale, many utilities have recently installed large photovoltaic arrays to provide consumers with solar-generated electricity, or as backup systems for critical equipment. Research into photovoltaic technology began over one hundred years ago. Conventional fuel sources have created myriad environmental problems, such as global warming, acid rain, smog, and water pollution, rapidly filling waste disposal sites, destruction of habitat from fuel spills, and the loss of natural resources. Photovoltaic systems do not pose these environmental consequences. Today, the majority of PV modules use silicon as their major component. Generally, the photovoltaic system could be grid connected or stand alone. The stand alone system mainly used for mobile remote area applications, they require energy storage system while almost 85% of photovoltaic system are grid connected that require no back-up energy storage system. Photovoltaic systems offer substantial advantages over conventional power sources: reliable, durable, low maintenance cost, no fuel cost, and pollution free. Though, photovoltaic have greater advantages, it also has some disadvantages when compared to conventional power systems which includes energy storage, and efficiency improvements.

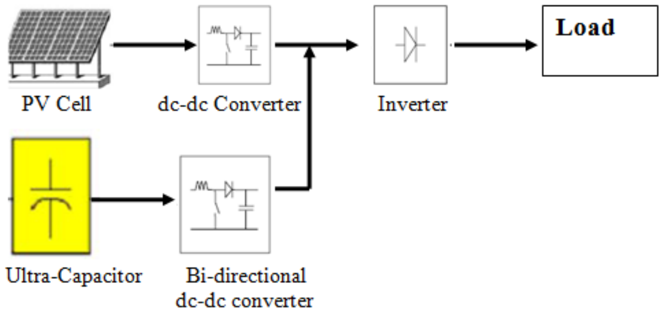

Fig. 1 Block diagram of a photovoltaic system

### A. *Photovoltaic Model System*

Modeling is the basis for computer simulation of a real system. It is usually based on a theoretical analysis of the various physical processes occurring in the system and of all factors influencing these processes. Mathematical models describing the system characteristics are formulated and translated into computer codes to be used in the simulation process. Photovoltaic cell models have long been a source for the description of photovoltaic cell behavior by researchers and professionals. The most common model used to predict energy production in photovoltaic cell modelling is the single diode circuit model that represents the electrical behaviour of the *pn*-junction as given in [16] - [20]. The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source ($I_{SC}$) as shown in Fig. 2, the equation for the output current is given by:

$$I_{SC} = [I_{SCT_1} + K_i(T_K - T_1)] * {}^{\sigma}/_{1000} \quad (1)$$

where $I_{SC}$ is the photocurrent in (A) which is the light-generated current at the nominal condition (25°C and 1000W/m$^2$), $K_i$ is the short-circuit current/temperature co-efficient at $I_{SC_{T_1}}$ (0.0017A/K), $T_K$ and $T_1$ are the actual and reference temperature in Kelvin (K), $\sigma$ is the irradiation on the device surface, and 1000W/m$^2$ is the nominal irradiation [20]. In the model, a current source $I_{SC}$ which depends on solar radiation and cell temperature; a diode in which the inverse saturation current $I_O$ depends mainly on the operating temperature; a series resistance $R_S$ and a shunt resistance $R_P$ which takes into account the resistive losses was considered [21].

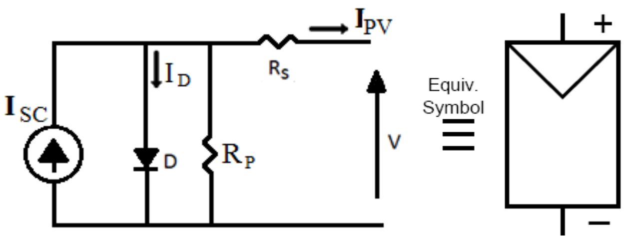

Fig. 2 Photovoltaic cell model

The basic equation that describes the current output of the photovoltaic (PV) module $I_{PV}$ of the single-diode model is as given in equation (8).

$$I_{PV} = N_p I_{SC} - N_p I_o \left\{ \exp\left( \frac{q(V_{PV} + I_{PV} R_S)}{N_S A k T_K} \right) - 1 \right\} - V_{PV} + \left(\frac{I_{PV} R_S}{R_P}\right) \quad (2)$$

The shunt resistance $R_P$ is inversely related with shunt leakage current to the ground. In general, the photovoltaic efficiency is insensitive to variation in $R_P$ and the shunt-leakage resistance can be assumed to approach infinity without leakage current to ground. For an ideal photovoltaic cell, there is no series loss and no leakage to ground, i.e. $R_S$ = 0 and $R_P = \infty$ [26]. Thus,

$$V_{PV} = \left(\frac{N_s k A T_K}{q}\right) \ln\left( {}^{(I_o + I_{SC} - I_{PV})}/_{I_o} \right) - I_{PV} R_S \quad (3)$$

where k is the Boltzmann constant (1.38 x $10^{-23}$ J K$^{-1}$), [9] q is the electronic charge (1.602 x $10^{-19}$ C), T is the cell temperature (K); A is the diode ideality factor, $R_S$ the series resistance (Ω) and $R_P$ is the shunt resistance (Ω). $N_S$ is the number of cells connected in series, $N_P$ is the number of cells connected in parallel, $V_{PV} = V_D = 20.76V$.The nonlinear and implicit equation depends on the incident solar irradiance, the cell temperature, and on their reference values [16]-[20].

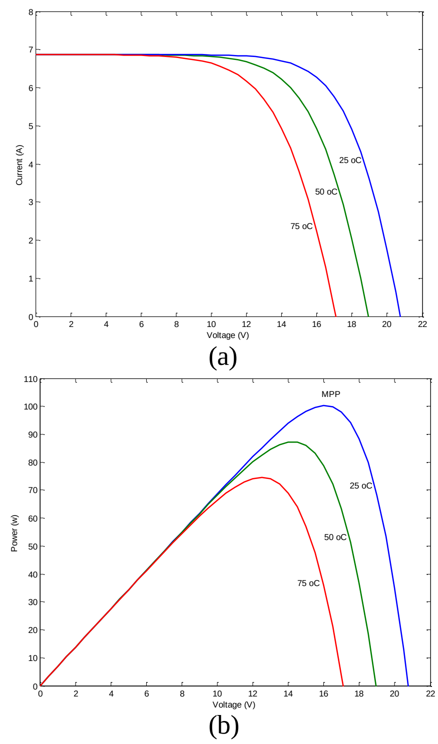

Fig. 3 (a) I-V and (b) P-V characteristic curve PV system

### B. *dc-dc Converter for Photovoltaic System*

Power converters are required to convert one form of electric energy to another. The stand-alone photo-voltaic energy system requires storage to meet the energy demand during the period of low solar irradiation and night time. Battery storage in a solar system should be properly controlled to avoid catastrophic operating condition like overcharging or frequent deep discharging. Storage batteries account for the most PV system failures and contribute significantly to both initial and the eventual replacement cost. Charge controllers regulate the charge transfer and prevent the battery from being excessively charged and discharged. A dc–dc converter is a power supply that converts a dc input voltage into a desired regulated dc output voltage. The dc input may be an unregulated or regulated voltage. Often, the input of a dc–dc converter is a battery or a rectified ac line voltage. A voltage regulator should provide a constant voltage to the load, even if line voltage, load current, and temperature vary. Switch mode DC to DC converters are used to match the output of a PV generator to a variable load. DC to DC converters allows the charge current to be reduced continuously in such a way that the resulting battery voltage is maintained at a specified value.

### *C. Bi-directional dc-dc converters*

The bidirectional dc-dc converter along with energy storage has become a promising option for many power related systems, including hybrid vehicle [25], fuel cell vehicle, renewable energy system and so forth. It not only reduces the cost and improves efficiency, but also improves the performance of the system.

In renewable-energy applications, the multiple-input bidirectional dc-dc converter can be used to combine different types of energy sources. In photovoltaic system applications, an auxiliary energy storage like an ultra-capacitor is been used. In addition, bidirectional dc-dc converter shown in Figure 1.1 is also required to draw power from the auxiliary ultra-capacitor to boost the high-voltage bus during the transient state [27]. With its ability to reverse the direction of the current flow, and thereby power, the bidirectional dc-dc converters are being increasingly used to achieve power transfer between two dc power sources in either direction.

Most of the existing bidirectional dc-dc converters fall into the generic circuit structure which is characterized by a current fed or voltage fed on one side [25]-[28]. Based on the placement of the auxiliary energy storage, the bidirectional dc-dc converter can be categorized into buck and boost type. The buck type is to have energy storage placed on the high-voltage side, and the boost type is to have it placed on the low-voltage side.

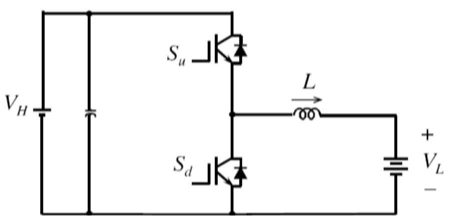


Fig. 4 Basic bidirectional dc-dc converter with buck and boost structure [27]

### *D. Inverter system for photovoltaic*

The inverter is needed for two reasons. First, the low DC voltage generated by the module must be amplified to the higher AC level in the grid. Second, the power delivered from the module(s) is very sensitive to the point of operation, and the inverter should therefore incorporate a function for tracking the Maximum Power Point (MPP). The most common PV-technologies nowadays are the single-crystalline silicon and the multi-crystalline silicon module(s) [29]. The open-circuit voltage in such a module is located in two ranges; either from 18 V to 26 V for a module made up of 36 cells or from 38 V to 46 V for a module composed by 72 cells [2]. However, new technologies like the thin-layer silicon, the amorphous-silicon and the Photo Electro Chemical (PEC) are in development [29]. This means that new modules with only one cell may see the light in the future. The voltage range for these cells/modules is located around 0.5 V to 2.0 V [30].

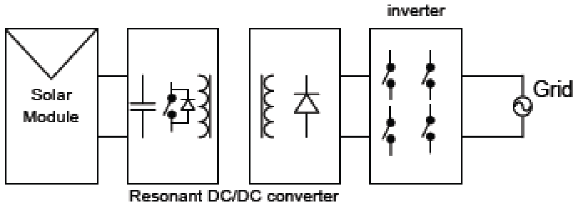


Fig. 5 Block diagram for modern photovoltaic inverter with two stages [26]

### *E. Inverter system topology*

Generally, there are three types of inverter topology used for photovoltaic system; these are the single-step, dual-step and the multi-step topologies for a.c. modules. Inverters for PV-applications have to contain some basic functionality. The conversion of the low voltage generated at the MPP (typically around 17 V for a 36 cells module and 34 V for a 72 cells module) to a corresponding AC current injected into the grid, must be done with the highest possible efficiency over a wide range of PV-power. This requirement is given due to the irradiation distribution of the sun that most of the power generated within the range is from 200 W/m2 to 1000 W/m2 of irradiation. The grid-connected stage in almost all the investigated solutions uses a full-bridge inverter towards the grid, either grid-commutated at twice the grid-frequency [ ] or self-commutated with a high switching frequency [31]. The grid commutated operation is possible if the input-current to the grid-connected stage is modulated to a rectified sinusoidal current. The latter utilizes PWM or bang-bang operation, and the benefits for the grid-commutated solution are that the switching losses from the stage are completely removed, and only the conduction losses remain. This means that the grid current must be sine-modulated in another sense, e.g. by the DC-DC converter. On the other hand, the switching losses are as a substitute moved to the module-connected converter. Another disadvantage is that both the module-connected converter and the grid-connected inverter must be designed for the peak power and not the average, which leads to larger and hence more expensive components.

## Maximum Power Point Tracking Techniques

Photovoltaic (PV) modules are semiconductors devices that are able to directly convert the incident solar radiation into electrical energy. On the I–V curve, there is a point called MPP (maximum power point) which always occur on the knee of the curve, where the generated PV power is maximized as shown in Fig. 3(b). Most of the maximum power point tracking point (MPPT) algorithms is control algorithm which searches the maximum power point (MPP) comparing the output power of the PV module before and after the duty cycle of the converter is changed [22].

In most of these algorithms, it is desired to optimise the power flow from the PV system to the load. When this is required, the operation point of the system must be maintained at the MPP. As the MPP depends on irradiation and temperature, these environmental conditions varies randomly, thus, the MPP position is constantly changed.

### *A. The Past: MPPT Techniques*

In the past, the most commonly used algorithm in PV maximum power point tracking systems are constant voltage, perturb and observe (P&O), seeking algorithm, sampling method, open circuit voltage, short circuit current, perturbation and observation method (P&O), the incremental conductance method (INC) and Hill climbing [9]. P&O method easily leads to erroneous judgement and oscillation around the maximum power point; it generally needs to combine one or several improvements for normal use. INC methods overcome these shortcomings of P&O methods but require relatively harsh detection devices and the choice of the step and threshold is also more stressful [10]. However, most of them use lengthy calculations, on-line sensed data or special circuit configurations.

### *B. The Present: MPPT Techniques*

At present, the fuzzy logic controllers (FLCs), neural network methods and particle swarm optimization (PSO) have received attention and increased their use very successfully in the implementation for MPP searching [32] –[36]. The fuzzy controllers improve control robustness and have advantages over conventional ones. They can be summarized in the following way [37]: they do not need exact mathematical models; they can work with vague inputs and, in addition; they can handle nonlinearities and are adaptative in nature; likewise, their control gives them robust performance, under parameter variation, load and supply voltage disturbances. Based on their heuristic nature and fuzzy rule tables, these methods use different parameters to predict the maximum power output: the output circuit voltage and short circuit current [37]; the instantaneous array voltage and current [37] – [38]; instantaneous array voltage and reference voltage (obtained by an offline trained neural network) [38]; instantaneous array voltage and current of the array and short circuit current and open circuit voltage of a monitoring cell [39] and solar radiation, ambient temperature, wind velocity and instantaneous array voltage and current, used in [40]. Other techniques based on different principles are fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc.

### *C. The Future: MPPT Techniques*

The conventional MPPTs are incapable of detect the global peak among all the peaks the P-V characteristic curve under changing weather conditions because once the algorithm meets a peak, it stuck within the peak and cannot rise to detect the rest of the peaks. Hence, those algorithms cannot assist the PV system to extract the maximum available PV power. By using the hybrid PSO and ANN algorithm, where the ANN was used to generate suitable values of $\Delta P$ and initial value of PV current to the PSO algorithm when there is a change of solar irradiance. The PSO algorithm then generates the PV current at MPP for the corresponding change of solar irradiance. Therefore, the PV system can always produce maximum power due to the PV current at MPP is detected by the algorithm even under varying weather condition. Therefore, the hotspot problem of the PV panel can be eliminated while the optimum PV energy is harvested.

## Discussion

In this paper, the state of the art of MPP algorithms has been reviewed. As it has been demonstrated, there are many ways of distinguishing and grouping the methods for tracking the MPP to the photovoltaic system. However, in this article, the past, present and future methods were those selected and emphasis in depth.

In terms of implementation, it is an important factor in deciding which MPPT technique to use. However, this greatly depends on the end-users' knowledge. Some might be more familiar with analog circuitry, in which case, fractional $I_{SC}$ or $V_D$, and load current or voltage maximization is good options. Others might be willing to work with digital circuitry, even if that may require the use of software and programming. Then, their selection should include hill climbing/P&O, IncCond, fuzzy logic control, neural network, and *dP/dV* or *dP/dI* feedback control. Furthermore, a few of the MPPT techniques only apply to specific topologies.

In terms of term of application, different MPPT techniques discussed earlier will suit different applications. For example, in space satellites and orbital stations that involve large amount of money, the costs and complexity of the MPP tracker are not as important as its performance and reliability. The tracker should be able to continuously track the true MPP in minimum amount of time and should not require periodic tuning. In this case, hill climbing/P&O, IncCond, are appropriate. Solar vehicles would mostly require fast convergence to the MPP. Fuzzy logic control, neural network, is good options in this case. Since the load in solar vehicles consists mainly of batteries, load current or voltage maximization should also be considered. The goal when using PV arrays in residential areas is to minimize the payback time and to do so, it is essential to constantly and quickly track the MPP. Since partial shading (from trees and other buildings) can be an issue, the MPPT should be capable of bypassing multiple local maxima. Therefore, the two-stage IncCond [31], [35] and the current sweep methods are suitable. Since a residential system might also include an inverter, the P&O MPPT can also be used. PV systems used for street lighting only consist in charging up batteries during the day. They do not necessarily need tight constraints; easy and cheap implementation might be more important, making fractional $V_D$ or $I_{SC}$ viable.

## Conclussion

Several MPPT techniques taken from the literature are discussed and analyzed herein, with their pros and cons. It is shown that there are several other MPPT techniques than those commonly included in literature reviews. The concluding discussion and table should serve as a useful guide in choosing the right MPPT method for specific PV systems.

## References

[1] J. H. Jung and S. Ahmed, "Model construction of single crystalline photovoltaic panels for real-time simulation," 2010, pp. 342-349.

[2] G. Walker, "Evaluating MPPT converter topologies using a MATLAB PV model," Journal of Electrical and Electronics Engineering, Australia, IE Aust, Vol. 21, No. 1, 2001, pp. 49-56.

[3] Yushaizad Yusof, et al, Modelling and Simulation of maximum power point tracker for Photovoltaic system, National power and energy conference, 2004 proceedings, Kuala Lumpur, Malaysia.

[4] A. K. Sinha, *et al.*, "Design and Testing of PV Maximum Power Tracking System with MATLAB Simulation," in *Tencon 2010: 2010 Ieee Region 10 Conference*, T. A. K. N. H. Okado, Ed., ed, 2010, pp. 466-473.

[5] A. Safari and S. Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter," IEEE Transactions on Industrial Electronics, vol. 58, pp. 1154-1161, Apr 2011.

[6] Issam Houssamo et al., Maximum power tracking for photovoltaic power system: development and experimental comparison of two algorithms, Renewable Energy, 2010 pp 2381-2387.

[7] A. Zegaoui et al, Comparison of two maximum power point trackers by simulating of PV generators, ScienceDirect, 2011 pp 678-687

[8] P. E. Kakosimos and A. G. Kladas, "Implementation of photovoltaic array MPPT through fixed step predictive control technique," *Renewable Energy,* vol. 36, pp. 2508-2514, Sep 2011.

[9] D. Peftitsis, *et al.*, *An investigation of new control method for MPPT in PV array using DC/DC buck - boost converter*, 2008.

[10] F. Liu, *et al.*, "A variable step size INC MPPT method for PV systems," *Ieee Transactions on Industrial Electronics,* vol. 55, pp. 2622-2628, Jul 2008.

[11] A.S. Samosir and A. H. M. Yatim, "Danymic evolution control for synchronous buck dc-dc converter, Theory, model and simulation, Elsevier, vol. 18, pp. 663-676, 2010.

[12] C.-H. Lin, et al., "Maximum photovoltaic power tracking for the PV array using the fractional-order incremental conductance method," *Applied Energy,* vol. 88, pp. 4840-4847, Dec 2011.

[13] R. V. Dell Aquila, "A new approach: Modelling, simulation, development and implementation of a commercial grid-connected transformerless PV inverter," 2010, pp. 1422-1429.

[14] R. M. da Silva and J. L. M. Fernandes, "Hybrid photovoltaic/thermal (PV/T) solar systems simulation with Simulink/Matlab," *Solar Energy,* vol. 84, pp. 1985-1996, 2010.

[15] L. Zhang, *et al.*, "A New Approach to Achieve Maximum Power Point Tracking for PV System With a Variable Inductor," *IEEE Transactions on Power Electronics,* vol. 26, pp. 1031-1037, Apr 2011.

[16] Kashif Ishaque, Zainal Salam and Hamed Tahri, 'Accurate MATLAB/*Simulink* PV systems simulator based on a two-diode model," journal of power electronics, vol. 11, No. 2, March 2011.

[17] B. Liu, *et al.*, *Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array*, 2007.

[18] N. Pandiarajan and Ranganath Muthu, Mathematical modelling of Photovoltaic module with Simulink, IEEE 2011, pp 258-263.

[19] Aissa Chouder et al, Modelling and simulation of a grid connected PV systems based on the evaluation of main PV module parameters, Sciverse ScienceDirect, 2011.

[20] W. Luo and G. Han, *The Algorithms Research of Maximum Power Point Tracking in Grid-connected Photovoltaic Generation System*, 2009.

[21] Y.-E. Wu, *et al.*, *Research and Improvement of Maximum Power Point Tracking for Photovoltaic Systems*, 2009.

[22] K. Tabaiya, *et al.*, *A Single-Phase Grid-Connected Inverter Using a Boost Two-Cell Switching Converter with Maximum Power Point Tracking Algorithm*, 2008.

[23] H. Zhang, "Study on Maximum Power Point Tracking for Grid-connected Photovoltaic System," in *Nanotechnology and Computer Engineering*. vol. 121-122, D. C. T. H. H. Z. D. H. L. Q. Wunsch, Ed., ed, 2010, pp. 93-96.

[24] K.-H. Chao and C.-J. Li, "An intelligent maximum power point tracking method based on extension theory for PV systems," *Expert Systems with Applications,* vol. 37, pp. 1050-1055, Mar 2010.

[25] I. Houssamo, *et al.*, "Maximum power tracking for photovoltaic power system: Development and experimental comparison of two algorithms," *Renewable Energy,* vol. 35, pp. 2381-2387, Oct 2010.

[26] M.A. Adbullah, et al., "A review of maximum power point tracking algorithms for wind energy systems" Renewable and Sustainable Energy Reviews, Vol. 16 pp. 3220-3227, June, 2012.

[27] M. Calais, V. G. Agelidis, "Multilevel converters for single-phase grid connected photovoltaic systems – an overview", IEEE proc. Of ISIE'98, vol. 1, pp. 224-229, July 1998, South Africa.

[28] F. Z. Peng, J. -S. Lai, "Multilevel cascade voltage source inverter with separate dc sources", US patent number: 5,642,275, June 1997.

[29] B. Verhoeven, et. al. *Utility aspects of grid connected photovoltaic power systems*, International Energy Agency PVPS task V, 1998.

[30] M. Meinhardt, D. Wimmer, G. Cramer, "Multi-string-converter: The next step in evolution of string-converter", Proc. of 9th EPE, 2001, Graz, Austria.

[31] M. Abou El Ela, J. Roger, Optimization of the function of a photovoltaic array using a feedback control system. Solar. Cells: Their Science,, Technology, Applications and Economics 13 (2) (1984) 185–195.

[32] S.M. Alghuwainem, Matching of a dc motor to a photovoltaic generator using a step-up converter with a current-locked loop, IEEE Trans. Energy Conversion 9 (1994) 192–198.

[33] T. Noguchi, et al., Short-current pulse-based adaptive maximum power point tracking for a photovoltaic power generation system, Elect. Eng. Japan 139 (1) (2002) 65–72.

[34] J.F. Schaefer, L. Hise, An inexpensive photovoltaic array maximum-power-point-tracking DC-to-DC converter. Number NMSEI/TN-84-1 New Mexico Solar Energy Institute, Las Cruces, New Mexico 88003, Mayo, 1984.

[35] Z. Salameh, F. Dagher, W. Lynch, Step-down maximum power point tracker for photovoltaic systems, Solar Energy 46 (5) (1991) 279–282.

[36] D.L. Lafferty, Coupling network for improving conversion efficiency of photovoltaic power source US4,873,480, 1989.

[37] K.K. Tse, H.S.H. Chung, S.Y.R. Hui, M.T. Ho, A novel maximum power point tracking technique for PV panels, in: IEEE Power Electronics Specialists Conference, 2001, PESC. 2001 IEEE, vol. 4, 1970–1975.

[38] N. Patcharaprakiti, S. Premrudeepreechacharn, Y. Sriuthaisiriwong, Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system, Renew. Energy 30 (11) (2005) 1771–1788.

[39] Reshmi C. Variath, Micheal A E A ndersen, Ole Neis Nielsen, Anders Hyldgard, " A review of module inverter topologies suitable for photovoltaic systems" 778-1-4244-7398-4/10, IEEE 2010.

[40] Yuvarajan S. And Shanguang Xu, " Photovoltaic power converter with a simple maximum power point traker" 0-7803-7761-0/03, IEEE 2003.

[41] Soeren Baekhoej Kjaer, John K, Pedersen, Frede Blaabjerg, " Power inverter topologies for photovoltaic modules- A review" 0-7803-7420-7/02 IEEE 2002.

[42] Dolar A, Foranda R, Leva S, " Energy comparison of seven mppt techniques for PV systems" journal of electromagnetic analysis and applications, vol. 3 page 152-162, 2009.

[43] Salas V, Olias E, Barrado A, Lazaro, " Review of the mppt algorithms for stand-alone photovoltaic systems" solar energy material and solar cells 90, page 1555-1578, 2006.