

# Critical Factors Affecting Efficiency of Maximum Power Point Tracking in Solar Cells

Priyank Srivastava<sup>\*1</sup>, Pankaj Gupta<sup>2</sup> and Amarjeet Singh<sup>3</sup>

## ABSTRACT

*A photovoltaic cell produces electrical energy directly from visible light. However, their efficiency is fairly low. So, the solar cell costs expensive as compared to other energy resources products. Various factors affect solar cell efficiency. This paper presents the most important factors that affecting efficiency of solar cells. These effects are cell temperature, MPPT (maximum power point tracking) and energy conversion efficiency. The changing of these factors improves solar cell efficiency for more reliable applications. There is a large energy demand due to industrial development and population growth especially in India. The main challenge in replacing conventional energy sources with newer and more environmentally friendly alternatives, such as solar and wind energy, is how to capture the maximum energy and deliver the maximum power at a minimum cost for a given load. The output power of photovoltaic cells or solar panels has nonlinear characteristics and these are also affected by temperature, light intensity and load.*

**IndexTerms :** Solar Cell, Efficiency, Cell Factor, Fill factor, Cell Temperature.

## 1. INTRODUCTION

Among various renewable and sustainable energy sources, solar energy provides the opportunity to generate power without emitting any greenhouse gas. The photovoltaic (PV) system technologies have increasing roles in electric power technologies, providing more secure power sources and pollution-free electric supplies. Photovoltaic power generation system can directly convert solar energy into electrical energy. The current - voltage output of photovoltaic battery is nonlinear, coupled with changes in the sunshine, temperature and other factors, the output power is constantly changing. The PV array can supply the maximum power to the load at a particular operating point which is generally called as maximum power point (MPP), at which the entire PV system

operates with maximum efficiency and produces its maximum power. Currently, PV modules have very low efficiencies with only about 12 “ 29% efficiency in their ability to convert sunlight to electrical power. Gallium Arsenide solar cells have a high efficiency of 29%, while Silicon solar cells have an efficiency of about 12-14%. The efficiency can drop further due to other factors such as PV module temperature and load conditions. In order to maximize the power derived from the PV module it is important to operate the module at its optimal power point. To achieve this, a controller called a Maximum Power Point Tracker is required[2].

Several factors affect solar cell efficiency. This paper examines the factors that affecting efficiency of solar cells according to scientific literature. These

- 1.\* Priyank Srivastava, Assistant Professor-I, Electrical & Electronics Engineering Department, School of Management Sciences, Technical Campus, Lucknow, India. e-mail : priyanksins@gmail.com
2. Pankaj Gupta, Assistant Professor-I, Electrical & Electronics Engineering Department, School of Management Sciences, Technical Campus, Lucknow, India. e-mail : panks226002@gmail.com
3. Amarjeet Singh, Associate Professor, Electrical & Electronics Engineering Department, School of Management Sciences, Technical Campus, Lucknow, India. e-mail : amarjeet11000@gmail.com

factors are changing of cell temperature, fill factor, using the MPPT with solar cell and energy conversion efficiency for solar cell[1].

## 2. STANDALONE SOLAR PV SYSTEM

A complete standalone solar PV system comprises of the following components, solar PV module(s), maximum power point tracker (MPPT), electrical load, charge controller, battery, inverter (for ac loads). Figure 1 represents a typical solar PV power system.

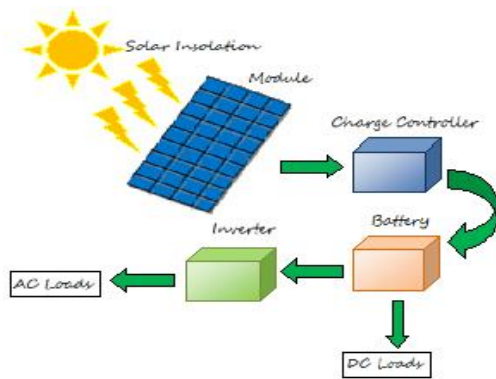


Fig.1: Typical Standalone Solar Photovoltaic System

## 3. PV MODULE CHARACTERIZATION

### 3.1 Electrical Circuit and Equations of Solar Cell

The characteristics of PV module are the basic requirement for tracking the maximum power points (MPPs) using any MPPT technique. For characterizing the solar PV module, it is required to model the characteristic equation from an electrical equivalent of solar cell (module) as in following figure 2:

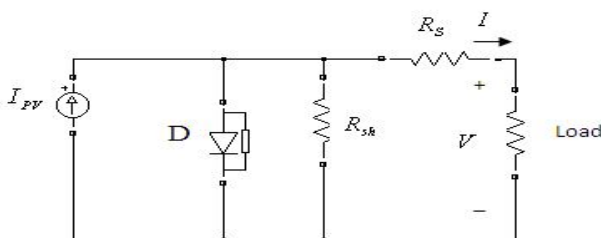


Fig.2: Equivalent Circuit of a Solar Cell

### 3.2 Photovoltaic Cell Characteristics

A PV module is composed of individual solar cells connected in series and parallel and mounted on a single panel. The goal is to calculate the power output from a PV module based on an analytical model that defines the current-voltage relationships based on the electrical characteristics of the module.

### 3.3 Photovoltaic Cell Mathematical Model and the Output Characteristics.

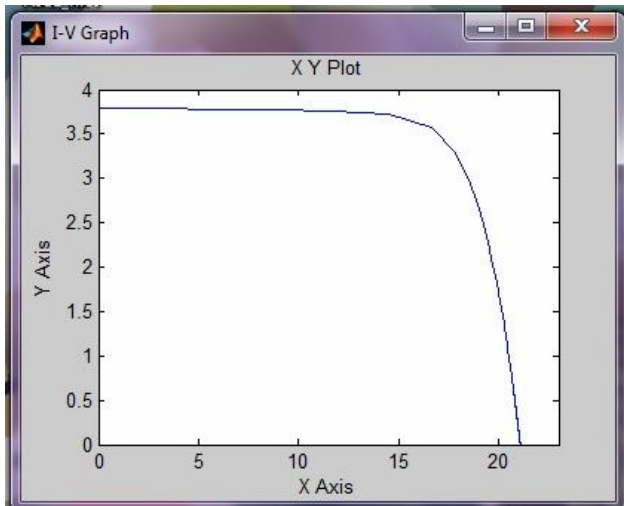
According to the electronic theory, the equivalent mathematical model of the photovoltaic cells is:

$$I = I_{sc} - I_0 \left[ \exp \left( \frac{V + IR_s}{AKT} \right) - 1 \right] - \frac{V + IR_s}{R_{SH}} \quad (1)$$

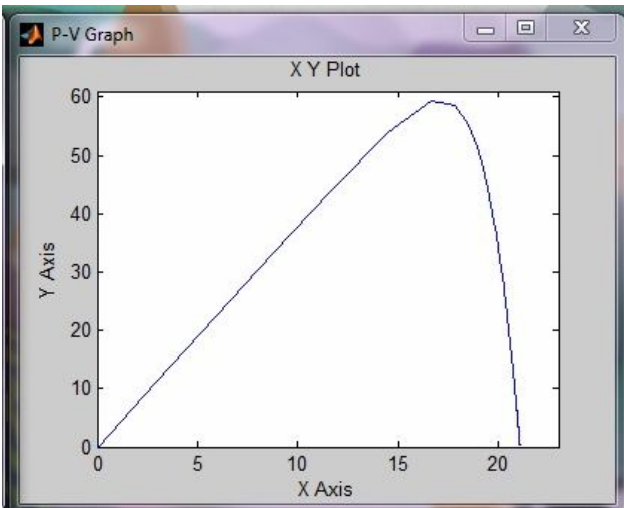
$$\text{Where } I_{PV} = [I_{pvr} + K_I (T - 298)] S / 100 \quad (2)$$

$$I_0 = I_{or} \left( \frac{T}{T_r} \right)^2 \exp \left[ \frac{qE_{co}}{AK} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right] \quad (3)$$

Where  $I$  and  $V$  is respectively the battery output current and port voltage;  $I_{pv}$  is the photocurrent;  $I_0$  is the battery internal equivalent diode PN junction reverse saturation current;  $q$  is the charge of an electron;  $A$  is diode PN junction ideality factor;  $K$  is the Boltzmann constant,  $1.38 \times 10^{-23} \text{ J/K}$ ;  $T$  is the operating temperature of photovoltaic cells;  $R_s$  is the battery's series resistance;  $T_r$  is the absolute temperature,  $273\text{K}$ ;  $I_{or}$  is the diode saturation drain current under  $T_r$ ;  $E_{co}$  is the width of silicon;  $S$  is the light intensity,  $\text{W/m}^2$ ;  $I_{pvr}$  is the short-circuit current under the conditions of  $298 \text{ K}$  and of  $1000 \text{ W/m}^2$ ;  $K_I$  is short-circuit current temperature coefficient under the conditions of  $I_{scr}$ . Affected by environmental factors such as light, temperature, the output characteristics of photovoltaic cells has the obvious nonlinear. Based on the above model can make the IV and PV curves of photovoltaic cells are as shown in Figure1.



Current-Voltage Characteristics



Power-Voltage Characteristics

**Fig.3:** The Output Characteristic of Photovoltaic Cell

## 4. SOLAR CELLS EFFICIENCY FACTORS

### 4.1 Cell Temperature

As temperature increases, the band gap of the intrinsic semiconductor shrinks, and the open circuit voltage ( $V_{oc}$ ) decreases following the p-n junction voltage temperature dependency of seen in the diode factor  $q/kT$ . Solar cells therefore have a negative temperature coefficient of  $V_{oc}(\beta)$ . Moreover, a lower output power results given the same photocurrent because the charge carriers are liberated at a lower potential. Using the convention introduced with the Fill Factor calculation, a reduction in  $V_{oc}$  results in a

smaller theoretical maximum power  $P_{max} = V_{oc} \times I_{sc}$  given the same short-circuit current  $I_{sc}$ .

As temperature increases, again the band gap of the intrinsic semiconductor shrinks meaning more incident energy is absorbed because a greater percentage of the incident light has enough energy to raise charge carriers from the valence band to the conduction band. A larger photocurrent results; therefore,  $I_{sc}$  increases for a given insolation, and solar cells have a positive temperature coefficient of  $I_{sc}(\alpha)$ .

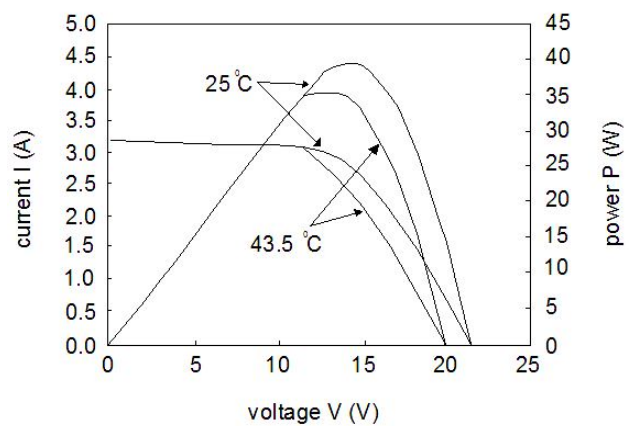
**Fig. 4:** I-V and P-V Characteristics of Solar Cell Module

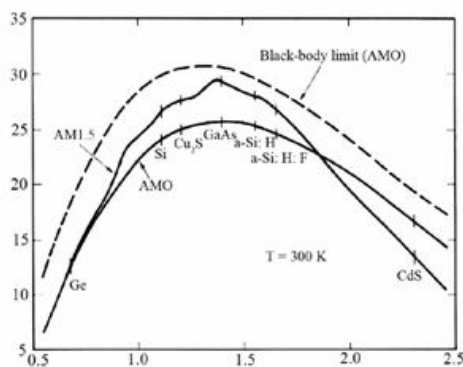
Figure 4 shows the I-V and P-V characteristics at the constant illumination when the temperature changes. Temperature effects are the result of an inherent characteristic of crystalline silicon cell-based modules. They tend to produce higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures. Any solar panel or system derating calculation must include adjustment for this temperature effect [1].

### 4.2 Energy Conversion Efficiency

A solar cell's energy conversion efficiency ( $\eta$ , "eta"), is the percentage of power converted (from absorbed light to electrical energy) and collected, when a solar cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point,  $P_m$ , divided by the input light irradiance ( $E$ , in  $W/m^2$ ) under standard test conditions and the

surface area of the solar cell ( $A_c$  in  $m^2$ ). The efficiency of energy conversion is still low, thus requiring large areas for sufficient insulation and raising concern about unfavorable ratios of energies required for cell production versus energy collected [12]. In order to increase the energy conversion efficiency of the solar cell by reducing the reflection of incident light, two methods are widely used. One is reduction of the reflection of incident light with an antireflection coating, and the other is optical confinements of incident light with textured surfaces. They showed that the transformation of the wavelength of light could significantly enhance the spectral sensitivity of a silicon photodiode from the deep UV and through most of the visible region.

The solar module has a different spectral response depending on the kind of the module. Therefore, the change of the spectral irradiance influences the solar power generation. The solar spectrum can be approximated by a black body of 5900 K which results in a very broad spectrum ranging from the ultraviolet to the near infrared. A semiconductor, on the other hand can only convert photons with the energy of the band gap with good efficiency. Photons with lower energy are not absorbed and those with higher energy are reduced to gap energy by thermalization of the photo generated carriers. Therefore, the curve of efficiency versus band gap goes through a maximum as seen from Figure 5 [2].



**Fig.5:** Dependency of The Conversion Efficiency on Semiconductor Band Gap

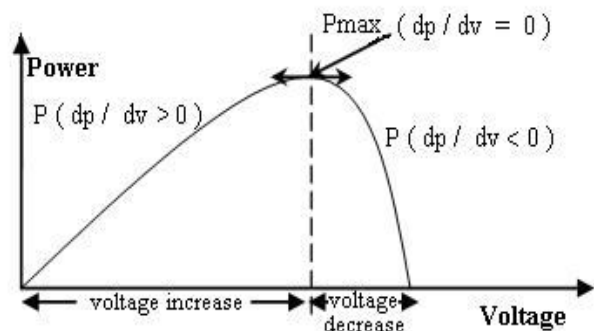
### 4.3 Maximum Power Point Tracking

Currently, the electricity transformation efficiency of the solar cells is very low that reach about 14%. The efficiency of solar cells should be improved with various methods. One of them is maximum power point tracking

#### 4.3.1 Principle of Maximum Power Point Tracking Control

The photovoltaic module operation depends strongly on the load characteristics, (Fig. 4 and 5) to which it is connected [14,]. Indeed, for a load, with an internal resistance  $R_i$ , the optimal adaptation occurs only at one particular operating point, called Maximum Power Point (MPP) and noted in our case  $P_{max}$ . Thus, when a direct connection is carried out between the source and the load, the output of the PV module is seldom maximum and the operating point is not optimal.

To overcome this problem, it is necessary to add an adaptation device, MPPT controller with a DC-DC converter, between the source and the load, (Fig. 6), [14]. Furthermore the characteristics of a PV system vary with temperature and insolation, (Fig. 7 and 8) [6, 7]. So, the MPPT controller is also required to track the new modified maximum power point in its corresponding curve whenever temperature and/or insolation variation occurs [14].



**Fig.6:** Power-Voltage Characteristic of a PV Module

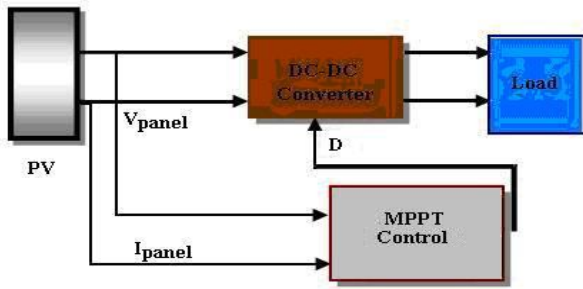


Fig.7: Photovoltaic MPPT System

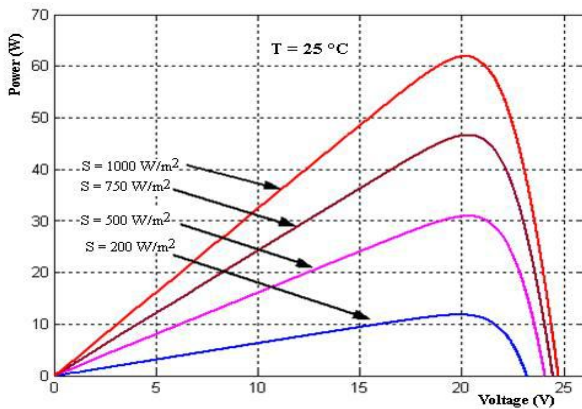


Fig.8: Influence of the Solar Radiation for Constant Temperature

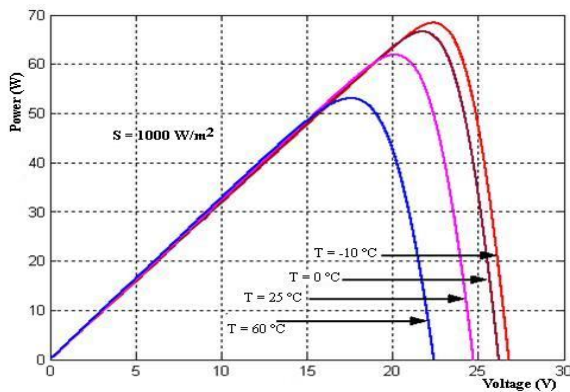


Fig.9: Influence of the Temperature of Junction for Constant Insolation

#### 4.4 Optimization of Area (Fill Factor) under the I-V curve

Mathematically we can state that the maximum possible area (product of voltage and current) formed by the intersection of horizontal line (voltage) extended to the I-V curve and vertical line (current) extended

to the I-V curve. The maximum power point is always present at the point of intersection of these extended lines from voltage axis (voltage at maximum power-  $V_{mp}$ ) and current axis (current at maximum power-  $I_{mp}$ ). This MPPT represents the maximum output power ( $P_o(\max) = V_{mp} \times I_{mp}$ ) extracted from the solar PV system to the electrical load. The rectangle formed by these two line represents the fill factor of the solar PV cell. The optimization of this parameter i.e. fill factor in turn ensures the higher efficiency of the overall solar PV system. The proposed methodology based upon fill factor maximization may be considered as the modified version of the constant voltage method based MPPT technique. The fill factor based mechanism has been illustrated in the following figure.

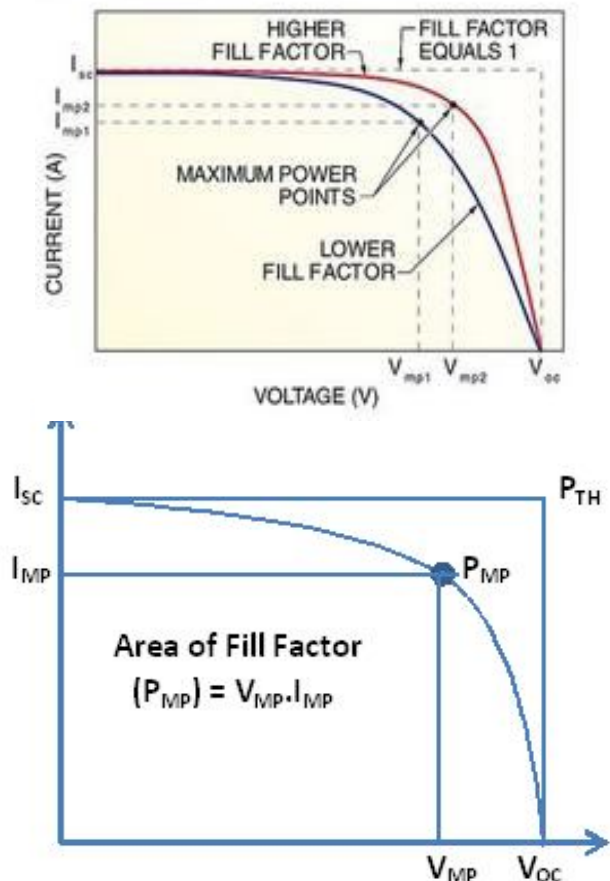


Fig.5: Fill Factor Representation



## 5. CONCLUSION

The paper examines the factors that affect efficiency of solar cells. These factors are changing of cell temperature, using the MPPT with solar cell, fill factor and energy conversion efficiency for solar cell. Temperature effects are the result of an inherent characteristic of solar cells. They tend to produce higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures. The energy conversion efficiency is increased by reducing the reflection of incident light. The function of the maximum power tracker is to change the equivalent load take by the solar cell array, and adjust the working point of the array, in order to improve the efficiency.

Changing of these factors is very critical for solar cell efficiency. The optimum factors make it possible to get the great benefits of solar electricity at a much lower cost.

## REFERENCES

- [1] FurkanDinger, Mehmet EminMeral. "Critical Factors that Affecting Efficiency of Solar Cells, Smart Grid and Renewable Energy, 2010, 1, 47-50
- [2] AryuantoSoetedjo\*, Lomi Abraham Yusuf Ismail Nakhoda, AwanUjiKrismananto, TELKOMNIKA, Vol.10, No.3, July 2012, pp. 419~430
- [3] Carvalho P. C. M. de, R. S. T. Pontes, D. S. Oliveira, D. B. Riffel, R. G. V. de Oliveira, and S. B. Mesquita, "Control method of a photovoltaic powered reverse osmosis plant without batteries based on maximum power point track-ing," in Proc. IEEE/PES Transmiss. Distrib. Conf. Expo.: Latin America, pp. 137-142, 2004.
- [4] EshamTrishan, and Chapman Patrick L., "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", IEEE Trans. On Energy Conversion, VOL. 22, NO. 2, pp. 439-449, 2007
- [5] Farada Roberto and Leve Sonia "Energy Comparison of MPPT techniques for PV Systems", WSEA Trans. On Power Systems, pp. 446-455, 2008.
- [6] Femia N., Granozio D, Petrone G. Spaguuolo G, and Vitelli M., "Optimized one-cycle control in photovoltaic grid connected applications," IEEE Trans. Aerosp. Electron.Syst., Vol. 42, pp. 954-972, 2006.
- [7] Hohm D. P. and Ropp M. E., "Comparative study of maximum power point tracking algorithms using an ex-perimental, programmable, maximum power point track-ing test bed," in Proc. Photovoltaic Specialist Conference, pp. 1699-1702, 2000.
- [8] Hsiao Y. T. and Chen C. H., "Maximum power tracking for photovoltaic power system," in Proc. Industry Application Conference, pp. 1035-1040, 2002.
- [9] Hua C. and .Shen C, "Comparative study of peak power tracking techniques for solar storage system," in Proc. APEC, pp. 679- 685, 1998.
- [10] Hussein K. H, Muta I, Hoshino T, and Osakada M, "Maximum power point tracking: an algorithm for rapidly chancing atmospheric conditions," IEE Proc.-Gener. Transm.Distrib., Vol. 142, pp. 59-64, 1995.
- [11] Karthika S. 1 ,Dr. Rathika P. 2, Dr. Devaraj D. 3 , International Journal of Computer Science and Management Research Vol 2 Issue 2 February 2013
- [12] Kawamura T., HradaK.,Ishihara Y, "Analysis of MPPT Characteristics in Photovoltaic Power System", Solar Energy Materials & SolarCells, Vol. 47, pp.155-165, 1997.
- [13] Kottas T. L., Boutalis S., and Karlis A. D., "New maximum power point tracker for PV arrays using fuzzy controller in close cooperation with fuzzy cognitive net-work," IEEE Trans. Energy Conv., Vol. 21, pp. 793-803, 2006.
- [14] M.S. AitCheikh\*, C. Larbes†, G.F. TchoketchKebir and A. Zerguerras, "maximum power point tracking control scheme", Revue des Energies Renouvelables Vol. 10 N°3 (2007) 387 – 395
- [15] Mekhilef S., Saidur R. and Safari A., "A Review of Solar Energy use in Industries", Elsevier Renewable and Sustainable Energy Reviews, Vol. 15, pp. 1777-1790, 2011.
- [16] MENG Onur Ozdal, ALTAS Ismail Hakkı , Turk J ElecEng& Comp Sci, Vol.20, No.2, 2012, c\_ TUBITAK

- [17] Park M. and Yu I. K., "A study on optimal voltage for MPPT obtained by surface temperature of solar cell," in Proc. IECON, pp. 2040–2045, 2004.
- [18] 1 Rahmani Rasoul, 2 Seyedmahmoudian Mohammadmehdi, 2Saad Mekhilef and 1Rubiyah Yusof, American Journal of Applied Sciences, 10 (3): 209-218, 2013
- [19] Salas V., .Olyas E, Barrado A, .Lazaro A, " Review of The Maximum Power Point Tracking Algorithms", Solar Energy Materials & Solar Cells, Vol. 90, pp. 1555-1578, 2006.
- [20] Lawrence k. letting, Design and implementation of fuzzy based mppt tracker, jomokenyatta university of agriculture and technology, 2008.
- [21] Sun X., Wu W "A research on photovoltaic energy controlling system with maximum power point tracking," in Power Conversion Conference, pp. 822–826, 2002.
- [22] TakunPongsakor, Kaitwanidvilai Somyot and ChaiyanJettanasen, IMECS 2011, Hong Kong.
- [23] Takashima T., Tanaka T., Amano M., and Ando Y, "Maximum output control of photovoltaic (PV) array," in Proc. 35<sup>th</sup> Intersociety Energy Convers. Eng. Conf. Ex-hib., pp. 380–383, 2000.
- [24] Valentini M., A. Raducu, D. Sera, R. Teodorescu, "PV inverter test setup for European efficiency, static and dynamic MPPT efficiency evaluation," in Proc. 11th International. Conference on Optimization of Electrical and Electronic Equipment, 2008, pp. 433-438.
- [25] Veerachary M. T. Senjyu, and Uezato K., Feed-forward maximum power point tracking of PV systems using fuzzy controller, vol. 38, no. 3, pp. 969–981, Jul. 2002.
- [26] Xuecheng Zhao 1,a, Yuhong Zhao 2,b, 2nd International Conference on Electronic & Mechanical Engineering and Information Technology (EMEIT-2012).

