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Effects of Surface Temperature Variations on Output Power of Three Commercial Photovoltaic Modules

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***Abstract* - An experimental study was carried out to investigate the effects of surface temperature and solar irradiance changes on the performance of three commercially available Photovoltaic (PV) modules, namely monocrystalline, polycrystalline and single junction amorphous, in three hot and days. Data were recorded for six hours per day starting from 10 am to 3 pm each day with a one-hour interval. Power output for each solar panel is calculated and compared to understand the behavior of temperature and sunlight on solar panels. Temperature change has acquired by varying air velocities on the surfaces of the panels to measure the power output of each PV modules separately and detailed presentation has been made through graphs in this paper. The results have shown that for mono-crystalline, polycrystalline, and single junction amorphous photovoltaic modules output power increases with the decrease in temperature on the surface of the each unit. The surge in output power is less for single junction module because it has large surface area and takes more time to cool down. Mono and polycrystalline panels output are higher than single junction panel because they have less number of cells in their module which result in quick temperature reduction on their surfaces.**

Keywords— Experimental, Photovoltaic Module; Solar Panel; Mono-Crystalline; Poly-Crystalline; Single Junction Amorphous; Power Output;

1. INTRODUCTION & BACKGROUND REVIEW

The demand for energy has increased many times in past two decades due to high industrialization. To overcome these energy crises our conventional energy sources are not enough due to high fuel prices so we have to find other energy resources. Solar energy is the best among these alternatives to generate energy. Solar radiations can be converted to electric energy by using Photovoltaic process. The development of affordable, inexhaustible and clean solar energy technologies will have huge and longer-term benefits. It will enhance sustainability and reduce pollution. A solar panel is a packaged, connected assembly of photovoltaic (PV) cells. Three main types of solar panel are tested in this investigation. Mono-crystalline silicon PV module is a form in which the crystal structure is homogenous throughout the material. Amorphous silicon PV module has no long-range periodic order [8] .The application of amorphous silicon photovoltaic cell is somewhat limited by its inferior electronic properties. Polycrystalline silicon PV module consists of small silicon crystals. It is the most efficient solar panel among all other types. The performance of photovoltaic modules in a place mainly depends on the climatic conditions like wind velocity, solar irradiance, the temperature of that place, dust particles and humidity etc. The significance of the temperature for the output of a photovoltaic module is studied comprehensively and recognized, as the worldwide focus of researchers has proved. There are many correlations exist which express PV temperature dependence on weather variables such as local temperature, local facility air speed and irradiance [9]. It was found that the photovoltaic panel temperature rise over the ambient is really delicate to wind velocity, less to air orientation, and least to atmospheric temperature [1]. Tripanagnostopoulos *et al.* [4] described experiments on photovoltaic thermal (PVT) liquid and air collectors for both amorphous and mono PV modules. Ji *et al.* [5] have reported an increased thermal harvest for a-Si. However, Affolter et al. [3] and Platz *et al.* [2] Zondag *et al.* [6] compared a conventional, glazed and unglazed modules for thermal efficiency and mean efficiency per annum.

2. ESSENTIAL COMPONENTS OF TEST RIG

An experimental rig was designed and fabricated from the local manufacturing facilities. Test facility consisted of two main components; wind tunnel and exhaust fan. The duct was setup in such a way that it should generate streamlined flow of air and not be interrupted by outside atmospheric wind. For laminar flow in duct hydraulic diameter, D_h has been calculated by perimeter via this relation [10],

$$D_h = \frac{S}{P}$$

Where, S is section of the duct, P is Perimeter of the duct

For rectangular duct, this above expression changes to this form,

$$D_h = \frac{a * b}{2(a + b)}$$

Where a is the width of the duct, b is the height of the duct. This diameter was multiplied by 10 to get streamline air flow passing PV modules for the sake of easy analysis. The duct had following dimensions,

Length = l = 4.5 m; Width = a = 0.8 m; Height = b = 0.2

The tunnel had a transparent square portion tightly sealed with glass to eliminate any possibility of air-mass leakage. The photovoltaic modules were put under this transparent glass to expose them directly to radiations. An exhaust fan was installed at one end to suck air through this channel passing over the surface of the panels. To obtain different air velocities, a regulator of 1500 W was used with a high resistance. In this study, three different types of commercially available PV modules were tested including monocrystalline silicon (c-Si),

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polycrystalline silicon (p-Si) and single junction amorphous silicon module (a-Si). The PV module was made of solid state semiconductor and converts incident sun rays falling on its surface into electricity through photovoltaic process. PV modules of different sizes, shapes, and capacity were used. The base material for the majority of PV modules was silicon.

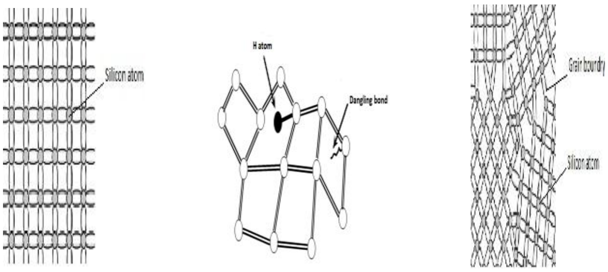

Fig. 1. Crystalline structures of three types of PV modules

c-Si p-Si a-Si

Crystalline silicon modules consisted of thin wafers of silicon particles. The two major types of crystalline silicon PV modules are mono-crystalline and multi-crystalline PV modules. The mono-crystalline PV module is well known for their high module output and efficiency. It consists of solar cells made from thin wafers of a single silicon crystal. The cells of polycrystalline panels are made up of thin layers of multi crystals grown together. The atoms in the polycrystalline cell do not have a uniform pattern as depicts in fig. 1. Furthermore, in mono all crystals have the same color but they vary in poly where shape of cells is square. The single and multi crystal PV modules had given outputs of 45W and 40W at standard test conditions (STC) with an area of 0.372 m² and 0.313 m² respectively. The amorphous module with its larger area had 15W manufacturer output, however, it was in continuous usage which reduced its wattage to 13W when calibrated. The decrease in output power was due to the degradation of in amorphous modules with time. This phenomenon is called Staebler-Wronski effect [7].

A pyranometer is a device to measure the global solar irradiance in a specific area. The Pyranometer with sensitivity 11.36 µV/Wm-2 was used it had spectral range 280-3000 nm. It was connected with solar radiation monitoring system which was displaying digital values of radiations and also recording. The stored data can be transferred to PC through its software. Module temperature was measured by using temperature sensors (k-type thermocouples). These temperature measuring devices were attached in the middle underneath each module with the help of a special heat conducting paste serving the purpose of getting precise readings. The thermocouple and Fluke digital multimeters were used in experiments have high accuracy and sensitivity for temperature measurement. A high resistance (50W single-turn) was used to act as a load to switch between the output current and voltage. This resistance was loaded-type with a ceramic body and bore current up to 3A. Standard test conditions (STC) are the typical settings at which PV panels are rated in a manufacturing environment using an artificial light source of irradiance 1000 W/m2, module temperature 25 °C and air mass (AM) 1.5. This standardization is given by the makers and labeled on the back side. The information given at STC includes Short circuit current (I_{sc}), Open circuit voltage (V_{oc}), Maximum power output (P_m), Current at Pm (I_m), Voltage at Pm (V_m), Fill Factor (FF), Efficiency (η_m) and Temperature coefficients.

Table 1. Manufacturer rated values for tested PV modules

	c-Si	*p-Si*	*a-Si*
Dimensions			
Module Dimensions (mm×mm)	690x 540	690 x 455	1250 x 640
Cell Dimensions (mm×mm)	156 x 52	156 x 52	1220 x 610
No. of Cells (in series)	4 x 9	4 x 9	1
Cell Area (m²)	0.292	0.2527	0.7442
Rated Values			
Maximum Power, Pmax (W)	45	40	15
Maximum Current, Imax (A)	2.2	2.3	0.42
Maximum Voltage, Vmax (V)	18.2	17.4	30.04
Short Circuit Current, Isc (A)	2.7	2.66	0.622
Open Circuit Voltage, Voc (V)	21.6	21.6	54.7

3. METHODOLOGY

The PV modules were placed inside a specially fabricated rectangular duct. The duct has two openings, at one end fan was installed to exhaust air at variable velocities and the other end remained open to allow atmospheric air mass. The PV modules were placed on a stand to facilitate air to pass beneath the surfaces of panels. A transparent glass was placed to focus light on photovoltaic cells assembly directly. An Anemometer (air-velocity measuring device) was used to measure velocities as needed. Values of current and voltage under different velocities and fan speeds were taken for calculating power output of each panel on hourly basis. Adjustable resistance was deployed for recording maximum power output. Resistance was varied and different voltages and currents values were taken correspondingly. Solar Irradiance was measured by using Pyranometer and solar radiation monitoring system. During each hour, readings of current and voltage, at four different velocities were taken. The data was collected and stored per hour from 10 in morning to 3 in afternoon in sunny days.

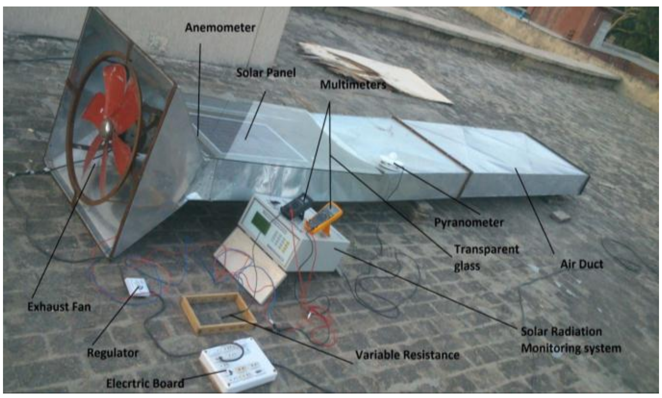

Fig. 2. Experimental setup with all components

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Table 2. Averaged values for different measured parameters

	Mono-crystalline	Poly-crystalline	Single junction Amorphous
Irradiance (W/m^2)	971.42	768.92	996.46
Average module temperature (°C)	57.07	60.18	68.54
Average Air Velocity	2.90	2.92	2.94
Avg. module power (W)	25.25	21.03	7.33
Avg. module efficiency (%)	8.92	10.90	0.97

This above table shows the mean values of all the variables for the panels under examination. This maximum power at output was the key concern to determine because all the performance related calculations based on this parameter.

A. Maximum Power Output Determination

The maximum power point was determined from current-voltage curve (I-V curve). Different investigators used different methods like I-V curve scans for measurement of P_m [11] while others have adopted custom made I-V curve measuring systems. We considered high power variable resistance for drawing I-V and P-V curves. The schematic circuit diagram for this investigation presented in fig. 3. These two curves were used to locate maximum power point. The voltage (V) was taken along the x-axis and current (I) on the y-axis. When resistance was kept zero, the voltage in the circuit became zero and maximum current flows in the circuit. This current, where voltage is zero called "short circuit current (I_{sc})". When resistance was increased gradually, the voltage surged and current decreased with the passage of time. At maximum resistance, current became zero and voltage reached its maximum value termed "open circuit voltage (V_{oc})". At a specific point, the current suddenly declined with a small growth in voltage to form a neck in I-V curve like fig. 4. Shows above,

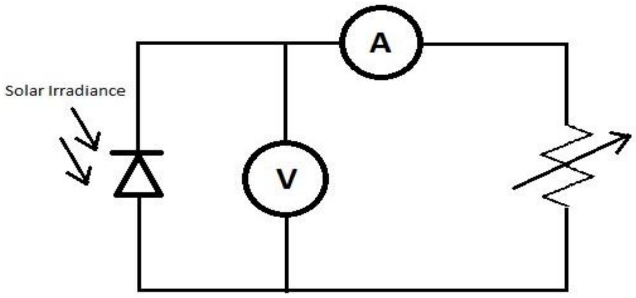

Fig. 3. Simplest Circuit Diagram for I_{sc} & V_{oc}

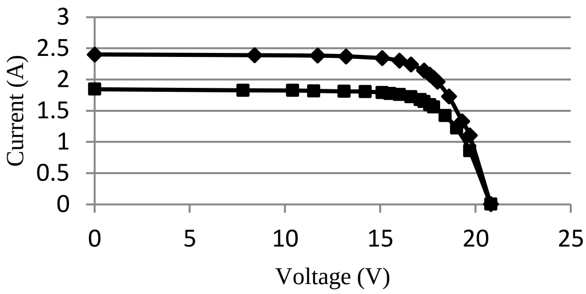

Fig. 4. I-V curve to find P_m

The maximum power point was located in the neck of I-V curve. The power at each point was obtained by multiplying current and voltage. The P-V curve was made by plotting P on y-axis and V on the x-axis. The top point of P-V curve is the maximum power point (P_m) of that curve as fig. 5 depicts,

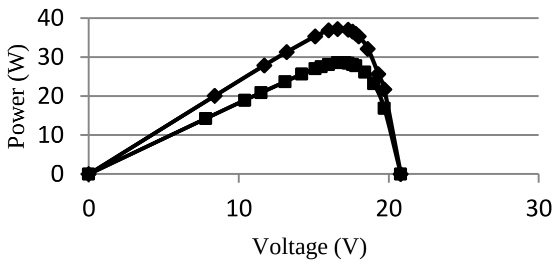

Fig. 5. P-V curve to find P_m

The current at maximum output point is said maximum current (I_m) and the voltage maximum voltage (V_m). The maximum power point P_m is the product of I_m and V_m [9, 11].

$$P_m = I_m \times V_m$$

4. RESULTS AND DISCUSSION

Data were collected for temperature and solar irradiance on the photovoltaic units for three consecutive days starting from morning at 10 till 3 in afternoon. Which were analyzed carefully to understand the influence it could have on solar panels output in real operating conditions. Graphs were developed to comprehend the trends of output power variations due to temperature and radiations. All the important findings have been detailed in this section with significant discussion to elaborate outcomes.

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A. Effects of Temperature and Irradiance on Power Output

Silicon solar modules were shown a decreasing trend in output power as the temperature on their surface rose. The decrement was different for each panel depending upon its cell structure, cells in a module and rated values at standard test conditions (STC). The first module placed in test rig was monocrystalline.

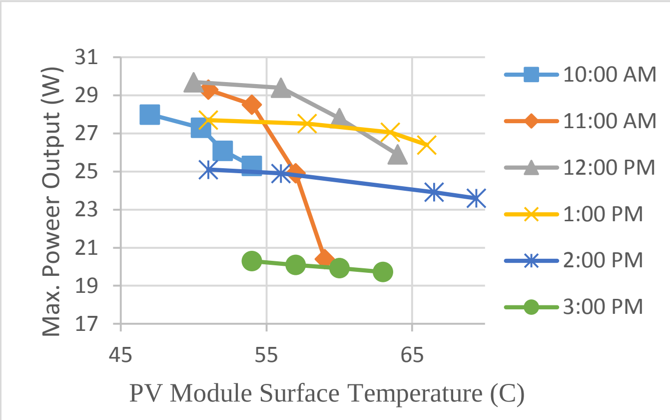

Fig. 6. Surface Temperature vs. Maximum Output Power for Monocrystalline PV Module

Single crystal panel had given maximum energy at the output on 12 pm and least at 3 pm in the afternoon. Figure 6 represents output for complete six hours. The power was highest when the fan was running at maximum designed speed at 12 pm comparing with other output values for the same panel with the same velocity of the fan. The reason behind this was a dip in temperature over panel surface with increasing velocity in intervals. At mid-day maximum irradiance was available straight perpendicular to the panel surface. Solar radiation graph tells these changes in irradiance with time in fig. 7. Polycrystalline was placed second in the facility to examine. It generated almost the same power like mono-module. Figures 8 and 9 show all the details for the polycrystalline module.

The Amorphous unit was of lowest output among all the three panels. It was converting maximum power between 12 and 1pm. It was suffering from higher temperature rise comparing to mono and polycrystalline due to its larger surface area

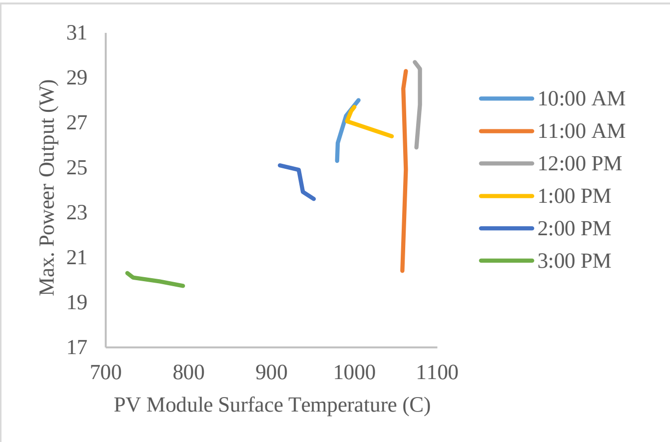

Fig. 7. Solar irradiance vs. Maximum Output Power for Monocrystalline PV Module

throughout the experimentation. The behavior for of this PV unit is shown in figures 10 and 11 which describe energy and irradiance unconventionality.

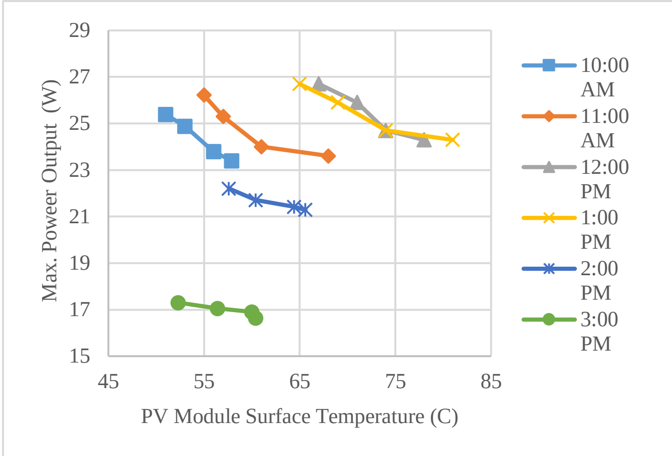

Fig. 8. Surface Temperature vs. Maximum Output Power for Polycrystalline PV Module

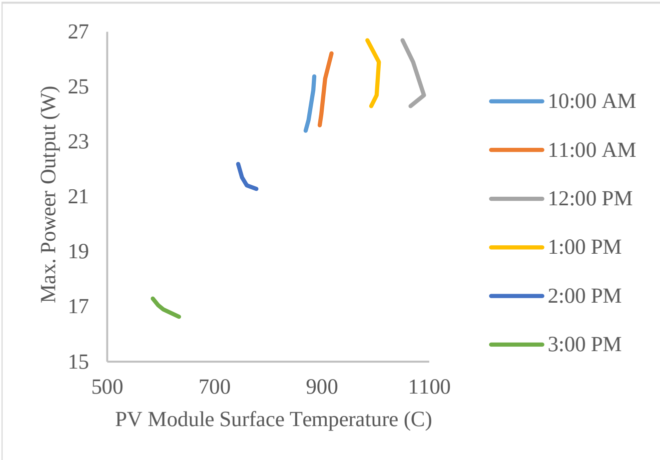

Fig. 9 Solar irradiance vs. Maximum Output Power for Polycrystalline PV Module

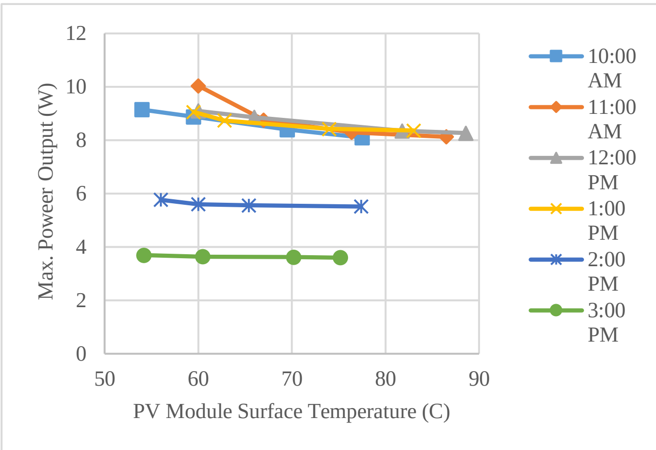

Fig. 10. Surface Temperature vs. Maximum Output Power for Amorphous PV Module

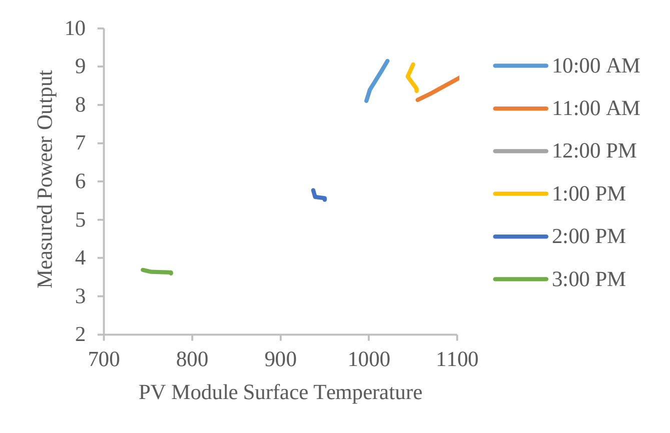

Fig. 11. Solar irradiance vs. Maximum Output Power for Amorphous PV Module

Wind velocity and temperature influence upon PV panels and their performance were not significantly described in the literature. The power available at output was reduced with a rise in temperature upon the surface of the panels from set test conditions. In the beginning, the most solar irradiance the more power output. The power output of all solar panels under study was increased with a decrease in surface temperature when exhaust fan ran at variable velocities. The average power output of examined panels was found always lower than the output power given by manufacturer at STC. It did not even approach the STC values. This happened because ambient temperature was always more than STC in the experimental environment. Accumulation of heat inside test duct where modules were placed over a stand also helped temperature to raise high. The fan was running at four different speeds each hour for every panel. These two factors permitted the surface temperature of modules to become shot resultantly energy available was declined. When exhaust fan was run at highest experimental velocity all the panels had given their maximum output power. When the fan was switched off least power was recorded as seen clearly from above plots. Hence, PV modules output was decreased with surface temperature rise. This behavior of PV modules is consistent with the outcomes presented by Dubey et al. and Hachicha et al. [9, 11] due to module temperature. Solar irradiance is another parameter which should be considered while determining the power of solar cells. The more solar irradiance the more power at output until the surface temperature becomes less than the STC. If the temperature goes above STC it would have an inverse effect and start decreasing output.

5. CONCLUSION

Photovoltaic electricity production is gifted technology to generate renewable energy from solar radiations. It is the best alternative and may play an important role in energy production in future. However, obtainable energy from solar technology greatly is dependent upon operating circumstances. PV cell performance is very much sensitive to cell surface temperature. This temperature is influenced by weather parameters like ambient temperature, wind velocity, humidity, solar irradiance, cell structure and material. In this regard, we tried hard to understand the influence of surface temperature and irradiance on PV modules to enhance output energy. Our investigation aimed to elaborate variations in energy production due to temperature. To keep cell temperature close to STC value, cooling methods (with the help of some fluid like air or water) should be developed, materials higher convective heat transfer should be used to manufacture these modules to reduce the module surface temperature.

REFERENCES

[1] J.S. Griffith, N.S. Rathod, J. Paslaski, “Some tests of flat plate photovoltaic module cell temperatures in simulated field conditions,” Proc. 15th IEEE Photovoltaic Specialists Conference, FL, pp.822-830, 1981.
[2] R. Platz, D. Fischer, M.A. Zufferey, J.A. Selvan, A. Haller, A. Shah, “Hybrid collectors using thin-film technology,” Proc. 26th Photovoltaic Specialists Conference, CA, 1997.
[3] P. Affolter , A Haller, D. Ruoss, P. Toggweiler, “A new generation of hybrid solar collectors Absorption and high temperature behavior evaluation of amorphous modules,” Proc. 16th European Photovoltaic Solar Energy Conference, UK, 2000.
[4] Y. Tripanagnostopoulos, Th. Nousia, M. Souliotis, P. Yianoulis, “Hybrid photovoltaic/thermal solar systems. Solar Energy,” vol. 72, pp. 217-234, 2002.
[5] J. Ji, T.T. Chow,W. He, “Dynamic performance of hybrid photovoltaic/thermal collector wall in Hong Kong,” Building Environment, vol. 38, pp. 1327-1334, 2003.
[6] H.A. Zondag, D. Vries, V. Helden, V. Zolingen, V. Steenhoven, “The yield of different combined PV thermal collector designs”, Solar Energy, 2003.
[7] Ko£Odziej, “Staebler-Wronksi effect in amorphous silicon and its alloy,” Opto-Electronics Review, vol. 12, pp. 21–32, 2004.
[8] P.E. Ugwuoke, Ph.D., C.E. Okeke, Ph.D., “Performance Assessment of Three Different PV Modules as a Function of Solar Insulation in South Eastern Nigeria,” international journal of Applied Science and Technology, Vol. 2, 2012.
[9] S. Dubey, J. N. Sarvaiya, B. Seshadri, “Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World A Review” Energy Procedia vol. 33, pp. 311 – 321, 2013.
[10] Caré, F. Bonthoux, J. R. Fontaine, “Measurement of air flow in duct by velocity measurements”, EPJ Web of Conferences, 2014.
[11] A. A. Hachicha, C. Ghenai, A. K. Hamid, “Enhancing the Performance of a Photovoltaic Module Using Different Cooling Methods,” International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering, vol. 9, 2015.