MATTER: International Journal of Science and Technology
ISSN 2454-5880

Ghosal et al., 2020

Volume 6 Issue 1, pp. 15-25

Date of Publication: 01st April 2020

DOI- https://doi.org/10.20319/mijst.2020.61.1525

This paper can be cited as: Ghosal, M. K., Sethi, A., & Behera, D. (2020). Performance of Solar Photovoltaic Module through Combined Air and Water Cooling in Warm and Humid Climatic Condition of India. MATTER: International Journal of Science and Technology, 6(1), 15-25.

PERFORMANCE OF SOLAR PHOTOVOLTAIC MODULE THROUGH COMBINED AIR AND WATER COOLING IN WARM AND HUMID CLIMATIC CONDITION OF INDIA

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Abstract

A study was conducted to evaluate the performance of solar photovoltaic module through combined air and water cooling arrangements in warm and humid climatic condition i.e. in Odisha in India during winter and summer months. Solar photovoltaic system requires neither fuel nor produces any pollutant resulting into its increased importance in today's energy sector. The electrical output from a solar panel is a function of its efficiency and some other controlling parameters which affects the same. One of the major parameters controlling the efficiency of the panel is the temperature as it goes on increasing while using the panel in the sun. About 31 % of the incident solar radiation on the panel is converted into the useful energy and the rest part is stored in its back side causing the rise of temperature and adversely affecting its output. The stored thermal energy is of no use and decreases the durability of the in-built components of the *panel due to the impact of severe thermal stresses on them resulting into reduction in its life span and conversion capability. The simplest way to enhance the efficiency of the panel is to incorporate the various cooling arrangements such as air cooling, water cooling and combined air and water cooling and assessing their effectiveness without any cooling arrangement. From the studies, it was observed that the efficiencies of solar panel were enhanced in the range of 8-11 %, 12-15% and 16-20% in air, water and combined air and water cooling respectively compared to without cooling in a clear day.*

Keywords

Solar Photovoltaic Module, Cooling of Photovoltaic Module, Efficiency of Photovoltaic Module, Tilt Angle for Photovoltaic Module

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1. Introduction

The importance of the applications of solar photovoltaic systems is increasing day by day due to the profuse availability of solar radiation in the tropical country like India. Solar photovoltaic system plays an important role that can make environment friendly, cost effective, more flexible and commercially widespread. That’s why it is mainly used in satellite power system, water pumping system and roof top electricity generation etc. (Bahaidarah et al 2013).

A typical PV module converts 6-20% of the incident solar radiation to electrical energy depends on the type of solar cells and climatic conditions. The rest of the incident solar radiation is converted into heat which ultimately increases the temperature of PV module and reduces the conversion efficiency of module as well as shortens the lifespan of solar cell resulting into the structural damage to the PV material (Chander et al 2015, Dubey et al 2009, Hossain et al 2008, Irwan et al 2015, Krauter 2004 and Linus et al 2018). The heat inside PV cell is created in two ways. First, because of thermal energy which is the difference between the absorbed solar photons and the electrical energy of the generated electron hole pairs. Second, there are I2Rs as result of the current flowing through the resistance Rs of the solar cell. The main disadvantage of solar cell is the decrease in its performance with respect to power output and electrical efficiency by the increase in the temperature of module (Muneer et al 2005, Radziemska 2003 and Rahman et al 2017).

There are various factors affecting the performance of solar cells such as solar radiation, temperature, humidity, air velocity, dust, orientation and tilt angle. Among these, temperature is the major factor affecting power output and the conversion efficiency of module. As cell temperature of module increases, efficiency of module decreases due to reduction in the voltage. As operating temperature of module increases, the open circuit voltage decreases significantly while short circuit current increases slightly and also the fill factor decreases. This leads to reduction of electrical power output and efficiency of solar cells (Sanusi et al 2011 and Teo et al 2012). Therefore, it is required to lower the temperature of solar cell as far as practicable in order to improve the conversion efficiency of PV cells. There are several cooling methods for regulating temperature of PV module such as air cooling, water cooling, cooling with phase change materials, heat pipe cooling, thermoelectric cooling, etc. (Xiao et al 2010). Cooling by the flow of air and water may be considered as the most effective method to provide an acceptable level of cooling for the PV cells. Therefore, the present research work was undertaken with the objective of studying the performance of solar PV module with the effects of operating parameters such as change of tilt angle and incorporating air and water cooling methods.

2. Materials and Methods

The experiments were conducted and the data were recorded in an interval of one hour from 9 am to 4 pm from December 2018 to April 2019 by installing the set up at the roof top of College of Agricultural Engineering and Technology, Bhubaneswar, Odisha (latitude 20.2650˚N and longitude 85.8117˚E). The place is coming under warm and humid climatic condition where the annual average rainfall is 1450 mm and average daily solar insolation is 4.8 kWh/m^2. During the course of investigation, important parameters recorded were solar radiation, ambient temperature, wind velocity, relative humidity and voltage, current and power output from the module. These parameters were recorded at an interval of 1 hour. Solar radiation was measured using solar irradiance meter. The details of the experimental set-up are shown in figure-1.

2.1 Experimental Setup

The layout details of the experimental setup have been shown below.

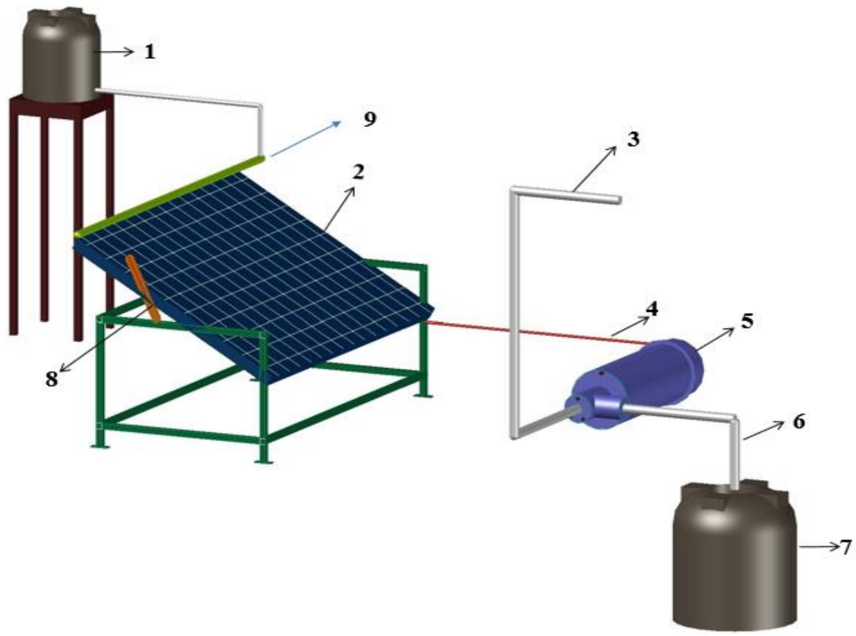

Figure 1: *Experimental Set-up for the Study*

1. Storage tank for flowing of thin film of water on solar module surface
2. Solar module
3. Water discharge pipe
4. Electrical connection from solar module to solar pump
5. DC solar pump
6. Suction pipe
7. Water tank for lifting purposes
8. Tilt angle adjustment arrangement
9. Perforated flexible pipe

2.2Components Incorporated in the Experimental Set-Up

Two solar photovoltaic modules were taken with similar specifications as mentioned below (Table-1). The solar modules were installed at a height of 1m from ground level and it was oriented in South direction. There was an arrangement provided to vary inclination of solar module with respect to the horizontal plane. Each solar module has 255W_p. As there were two modules, the total wattage was 510W_p, which was sufficient to run a 0.5 hp DC water pump. In order to measure the different electrical parameters in connection with evaluation of solar pump used for the study, a solar testing kit was used. It measures the parameters such as ambient air temperature, solar radiation, current, voltage, fill factor of solar module.

Table 1: *Specifications of Solar Module*

Parameter	Specification
Type of solar module	Poly crystalline
Panel connection	Series
Panel dimensions	100cm×166cm×4cm
Maximum power	255 W_p
Total power of module	2×255 W_p = 510 W_p
Open circuit voltage	37.69V
Short circuit current	8.89A
Voltage at maximum power	30.33V
Current at maximum power	8.41A

The instruments used for the measurement of experimental data were solar irradiance meter, SEWARD PV 200 analyser for measuring electrical parameters to calculate efficiency of module.

For air cooling purpose, four number of fan are attached on the backside of the PV module shown in Figure-2 and specifications are given in Table-2. For effective cooling, fans were operated from 9 am to 4 pm continuously for removing the heat stored in the back side of the module resulting into the lowering of its temperature. The operation of fan is controlled by a charge controller. The fans were powered from the modules used for the study.

Figure 2: *Arrangement for Air Cooling*

Table 2: *Specifications of DC Fan*

Type of fan	DC
Manufacturer	San Ace 120
No of fan used	4
Voltage	12V
Current	0.83A

For water cooling, a perforated flexible pipe is used and small holes of 2-3mm are made on the flexible pipe. Water is allowed to flow from the storage tank by the gravitational force. A very thin film of water flows over the surface of the module for effective cooling through evaporation of water.

Figure 3: *Arrangement of Water Cooling of Module*

The storage tank was placed in one side and at a height of 2 meter from the upper surface of the module. The set up for water cooling is shown in Figure-3.

3. Results and Discussions

The results in this section consist of two parts. In the first part, the tilt angle of the solar module was decided to fix for the study on the basis of the maximum availability of incident solar radiation on it in the experimental site from January to April. In the second part, all the electrical parameters such as short circuit current, maximum current, open circuit voltage, maximum voltage, fill factor of the used solar module were measured on hourly basis from 9 am to 4 pm along with the incident solar radiation on the surface of the module with the help of solar PV analyzer. The data were recorded by following various cooling methods such as air, water and combined air and water cooling separately and compared these without any cooling method. The efficiency of the solar module is calculated from the measured data and compared with those in case of without using any cooling method.

3.1 Fixing the Tilt Angle of Solar Modules used under Study from January to April

The incident solar radiation on the horizontal as well as inclined surface varies from morning to the afternoon due to the change of altitude angle of sun in a day during its movement in the sky. In order to harvest more solar radiation from any solar device, the tilt angle of the surface needs to be changed on hourly basis in a day or with the change of the season in a year. Without any tracking arrangement, the tilt angle needs to the fixed in a month in a particular location and site in order to get the availability of more solar radiation on the module. The data for the availability of incident solar radiation were measured from 9 am to 4 pm on clear day during January to April 2019 and have been presented in the Figure-4. From the data collected, it was observed that the availability of incident solar radiation was recorded to be maximum at the tilt angle of 35^0, 30^0, $20^0$and 8^0 respectively in the month of January, February, March and April 2019 for the experimental set up located in the roof top of the College of Agricultural Engineering and Technology, OUAT, Bhubaneswar, Odisha. Accordingly, the tilt angle was fixed in each month and data were recorded for the present study.

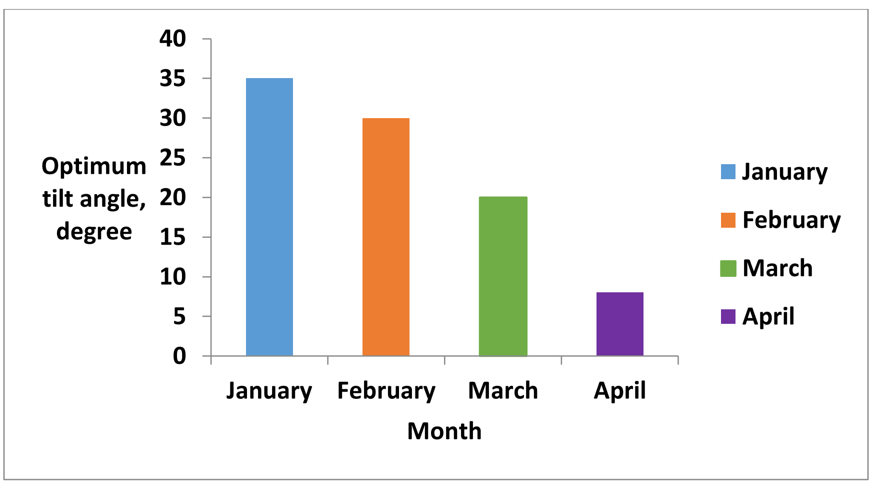

Figure 4: *Fixation of Tilt Angle of Module during January-April 2019*

3.2 Measurement of Electrical Parameters of Solar Module used for the Study

Hourly variations of solar radiation, ambient air temperature, module back surface temperature, short circuit current, open circuit voltage, current at maximum power point, voltage at maximum power point, fill factor and efficiency of solar module on clear days during January to April 2019 with respect to various cooling arrangements were studied. Data were collected in four consecutive days by following without cooling, cooling with air, water and combined air and water separately and efficiency of the module was compared with respect to without cooling. From the figure 5, it was observed that the temperatures of solar module were decreased in the range of 4-5 ˚C, 6-8 ˚C and 9-12 ˚C in air, water and combined air and water cooling respectively compared to without cooling in a clear day. Also, it was observed from figure 5, the efficiencies of solar module were increased in the range of 8-11 %, 12-15% and 16-20% in air, water and combined air and water cooling respectively compared to without cooling in a clear day.

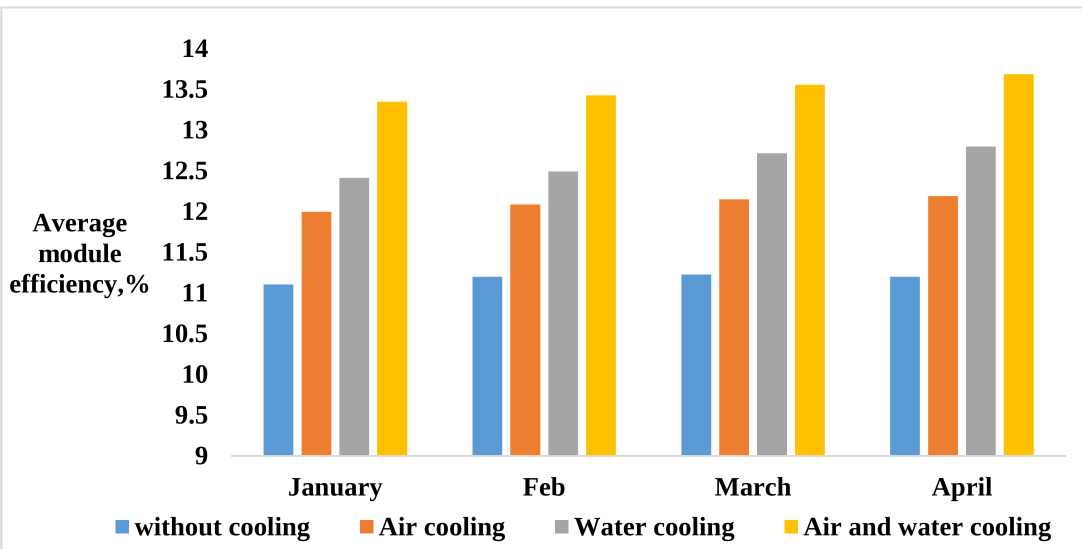

Figure 5: *Variations of Module Efficiency with Different Cooling Arrangements from January to April 2019*

For air cooling purpose, 4 no of fans were fitted to reduce module temperature. From the figure above, it was found that with air cooling, module efficiency increased as open circuit voltage, fill factor, power output increased. Due to cooling by exhaust fan, temperatures of module were maintained. So output voltage was increased. Efficiency was calculated to be maximum at noon then decreased as per the changes in the availability of solar radiation. The module temperatures were maintained and their efficiency was increased compared to without cooling. The decrease in temperature of the back surface of the module may be attributed due to the dissipation of stored thermal energy from the back surface by convection to the outside through the continuous flow of air with the help of DC fan, powered by the module itself.

In case of water cooling, thin film of water was allowed to flow on the upper surface of the module, resulting into a cool environment due to evaporation of water. The thermal energy at the back surface was decreased due to the spread of cool air at a lower temperature surrounding the module.

In combined air and water cooling, the decrease of temperature was found to highest due to the simultaneous effects of flowing of air flow and spread of cool evaporated air both on the lower and upper surface of the module. In case of without cooling technique, with increase of solar radiation and ambient air temperature, the temperatures of the back surface of the module increased in the range of 50 to 60˚C resulting into the decrease in the power output and thus efficiency of the module.

4. Conclusions

One of the practical and viable solutions for enhancing the efficiency of the solar photovoltaic panel for a user is to incorporate various cooling arrangements for dissipating stored thermal energy in its back side. This is under the control of the user. This proposition also depends on the climatic conditions where the panels are used. A lot of research activities have been undertaken by the various researchers to increase the output of the solar panel. The present study has been carried out in warm and humid climatic condition by incorporating air, water and combined air and water cooling arrangements for a solar panel and the following conclusions were drawn out of it. The Average solar radiation in a clear day was found to be highest at tilt angle of 35˚, 30˚,20˚,8˚ in month of January, February, March, April respectively. The temperatures of solar panel were decreased in the range of 4-5 ˚C, 6-8 ˚C and 9-12 ˚C in air, water and combined air and water cooling respectively when compared to without cooling in a clear day. The efficiencies of solar module were increased in the range of 8-11 %, 12-15% and 16-20% in air, water and combined air and water cooling respectively compared to without cooling in a clear day. The above findings would not only be helpful for the researchers but also for the manufacturers and users for the climatic condition under study. The manufacturers may keep the provision of air or water cooling conduits in the back side of the panel for its easy use and cooling, resulting into the enhancement of efficiency by 10-15 %.

References

Bahaidarah, H., Subhan, A., Gandhidasan, P., & Rehman, S. (2013). Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. Energy, 59, 445–53. https://doi.org/10.1016/j.energy.2013.07.050

Chander, Subhash., Purohit, A., Sharma, Anshu., Nehra, S.P., & M.S. Dhaka. (2015). Impact of temperature on performance of series and parallel connected mono-crystalline silicon solar cells. Energy Reports, 1,175–180. https://doi.org/10.1016/j.egyr.2015.03.004 https://doi.org/10.1016/j.egyr.2015.09.001

Dubey, S., Sandhu, G. S., & Tiwari, G. N. (2009). Analytical expression for electrical efficiency of PV/T hybrid air collector. Appl Energy, 86(5), 697–705. https://doi.org/10.1016/j.apenergy.2008.09.003

Hossain, E, Muhida, R, & Ali A. (2008). Efficiency improvement of solar cell using compound parabolic concentrator and sun tracking system. In: EPEC Electric Power Conference. 2008, 1-8 https://doi.org/10.1109/ICCITECHN.2008.4803090 https://doi.org/10.1109/EPC.2008.4763293

Irwan, Y. M., Leow, W. Z., Irwanto, M., Fareq, M., Amelia, A.R., & Gomesh, N. (2015). Indoor test performance of PV panel through water cooling method. Energy Procedia, 79, 604–611. https://doi.org/10.1016/j.egypro.2015.11.540

Krauter, Stefan. (2004). Increased electrical yield via water flow over the front of photovoltaic panels. Solar Energy Materials and Solar Cells, 82, 131-137. https://doi.org/10.1016/j.solmat.2004.01.011

Linus, Idoko., Olimpo, Anaya-Lara., & Alasdair, McDonald. (2018). Enhancing PV modules efficiency and power output using multi-concept cooling technique, Energy Reports, 4, 357–369. https://doi.org/10.1016/j.egyr.2018.05.004

Muneer, T., Asif, M., & Munawar, S. (2005). Sustainable Production of Solar Electricity with Particular Reference to the India Economy. Renewable Sustainable Energy Review, 9, 444-473. https://doi.org/10.1016/j.rser.2004.03.004

Radziemska, E. (2003). The effect of temperature on the power drop in crystalline silicon solar cells. Renew Energy, 28(1), 1–12. https://doi.org/10.1016/S0960-1481(02)00015-0

Rahman, M.M., Hasanuzzaman, Md., & Rahim, N.A. (2017). Effects of operating conditions on the energy efficiency of photovoltaic modules operating in Malaysia. Journal of Cleaner Production, 143, 912-924. https://doi.org/10.1016/j.jclepro.2016.12.029

Sanusi, Y. K., Fajinmi, G. R., & Babatunde, E. B. (2011). Effects of Ambient Temperature on the Performance of a Photovoltaic Solar System in a Tropical Area. The Pacific Journal of Science and Technology, 12(2): 177-180.

Teo, H.G., Lee, P.S., & Hawlader, M.N.A. (2012). An active cooling system for photovoltaic modules. Appl. Energy, 90, 309–315. https://doi.org/10.1016/j.apenergy.2011.01.017

Xiao, Tang., Quan, Zhen hua., & Zhao, Yaohua. (2010). Experimental investigation of solar panel cooling by a novel micro heat pipe array. Energy Power Eng, 2, 171–174. https://doi.org/10.4236/epe.2010.23025