iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** XI **Month of publication:** November 2016

DOI:

www.ijraset.com
IC Value: 13.98

Volume 4 Issue XI, November 2016
ISSN: 2321-9653

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Performance Analysis of Actively Cooled Solar PV Panel Subjected to Concentrated Radiation

Mr. Aniket M. Gajbhiye[1], Prof. Bhojraj N. Kale[2]

[1](Research Scholar, DBACER, Department of Mechanical Engineering, Nagpur University, Nagpur, India)

[2](DBACER, Department of Mechanical Engineering, Nagpur University, Nagpur, India)

Abstract: Solar energy is converted into electrical energy by solar photovoltaic panels. These photovoltaic panels are named as solar PV panels or modules. The amount of electricity generated by these panels is directly proportional to the surface area of the panels and the intensity of incident solar radiation striking its surface etc. Solar panels thus produces electrical energy by converting solar energy which is incident on its surface, but it is observed that the amount of energy which is incident on the surface of the panels does not completely converted into electrical energy and most of the energy is lost. The important factor responsible for loss of solar energy to get converted into electrical energy is the increase in temperature of solar cells. As the temperature of the solar cell increases the band gap between the valance band and conduction band decreases which results in the reduction of open circuit voltage (V_{oc}). Thus, to get the higher electrical output we must keep the temperature of the solar cell/ panel as low as possible to obtain higher electrical efficiency. In this report we have discussed the effect of active cooling mechanism which kept the temperature of the solar PV panel towards lower side by using normal water and salt water with 3.5% concentration as coolant, moreover we used the system of mirrors to concentrate the solar radiation on the solar PV surface which is called as V-trough concentrator system. We have tested the properties of solar panel by using different instruments and extracted the heat from the solar PV module. Salt water with 3.5% concentration is used as coolant because if the system is installed on the small islands where conventional electricity cannot be transmitted, we can use filtered sea water and can cool the PV panels. The standard sea water has 3.5% concentration of salt.

Keywords: Solar PV, Solar PV/T,Solar cell,Solar Panel/Module, Semiconductor,Open circuit voltage (Voc), Short circuit current (Isc).

I. INTRODUCTION

The solar cell is used for converting solar energy into electrical energy by using the principle of photoelectric effect. These solar cells are made up of semiconductor material silicon with no moving parts. When suns radiation strikes the solar cell it gains the energy of photons present in sunlight and free electrons are generated which jumps from the valance band to conduction band in semiconductor molecule to conduct electricity. The space between the energy level of valance band and conduction band is called band gap. This band gap acts as a barrier to the electrons in valance band and thus, whenever electrons overcomes this barrier the potential difference is obtained across the terminals of solar cell. Thus, the electrons require certain minimum energy to overcome the band gap which it gets from the photons striking it. The band gap is directly proportional to open circuit voltage of semiconductor. With the increase in intensity of solar radiations number of free conducting electrons increases and thereby results in higher electrical output which is given by open circuit voltage (Voc) and short cicuit current (Isc).The increase in solar radiation intensity also results in the increase in temperature of solar cell as only few part of solar energy gets converted into electrical energy and remaining energy is converted into heat. This heat produced increases the cell temperature and the electrons in the valance band reaches at higher initial energy state. This results in the reduction of the band gap which ultimately reduce Voc resulting in lower electrical output. Thus, with the increase in solar cell temperature electrical output decreases.

The available literature shows that researchers are concerned to improve the electrical output, electrical efficiency by cooling the solar PV panel using mostly atmospheric air and normal water. The heat which is extracted by these coolants can be further utilized for other applications such as for domestic purpose or for process heat in small industries. This heat extraction results in the improvement in electrical efficiency as well as thermal efficiency of the system. As the system gives electrical output by using solar PV and thermal output by extracting heat from solar PV, the system is called as solar PV/T system, where PV/T stands for photovoltaic thermal system. The advantages of PV/T system is improved electrical and thermal efficiency which gives improved overall efficiency. Researchers also worked on concentrating the solar radiations on the solar PV panel surface by using different mechanisms such as parabolic trough concentrator, V trough concentrator, Fresnal lens etc. This resulted in improved thermal output and overall efficiency of the solar PV/T system as more heat in the form of solar radiation is incident on the solar PV panel. In the present system we have designed solar PV/T system by directly passing coolants such as normal water and salt water of 3.5% concentration from the channel provided below the solar PV panel and also concentrated the solar radiations by using V-trough concentrator system as shown in Fig1. The salt water of 3.5% concentration is used as coolant for performance analysis of panel if cooled with filtered sea water on remote islands where conventional power plant cannot transmit the electricity. For such places where solar power plants are installed sea water could be used as coolant directly for improving electrical performance and for extracting heat which can be used for different purposes on the remote islands. The average sea water concentration of salt which is 3.5%[1]. Thus, 1 liter or nearly 1 Kg of water contains 35grams of salt. The analysis of salt water of 3.5% as coolant is considered for this purpose.

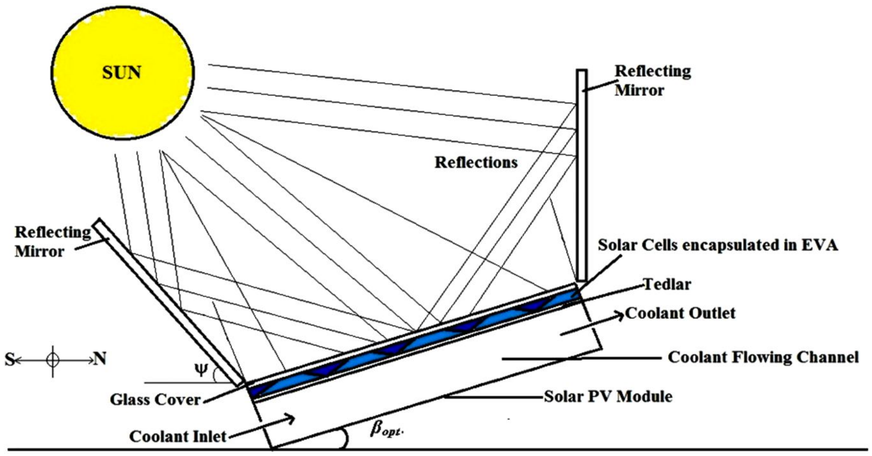


Fig 1. V-trough concentration system and cooling system for PV module

We have compared the experimental data of concentrated system with the un-concentrated system for the performance analysis at the Nagpur location, Maharashtra, India having co-ordinates 21.09^0N,79.05^0E. The experiment was carried on four consecutive clear solar days dated 15^{th} , 16^{th} ,17^{th} and 18^{th} April 2016. The different parameters were noted and tabulated by using different instruments and components. For these four days we assigned four conditions for performance analysis of PV module respectively. These conditions are as follows:

Condition 1: Without Concentration without cooling of PV module.

Condition 2: Without Concentration with cooling of PV module with water as coolant.

Condition 3: With Concentration with cooling of PV module with water as coolant.

Condition 4: With Concentration with cooling of PV module with salt water as coolant.

II. EXPERIMENTAL SETUP

For the conduction of experiment 20Watts solar panel of VIKRAM SOLAR ELDORA20P module is tested by sealing and insulating the back side of the panel with thin Aluminium sheet with Araldite epoxy glue. Single inlet and single outlet is provided for the fluid flow below the PV module surface. The panel is fitted into the base made of cast iron and the two reflecting mirrors of 4mm thickness are provided which can be fixed at any angle greater than 90^0 with respect to solar PV surface shown in Fig 2. The present system does not track the sun by changing its angle, thus for optimizing the solar radiation striking the PV surface over the whole year the module needs to be tilted at an angle 3^0 with the horizontal for the month of April, May, June, July [2] for Nagpur location. This tilt angle of the PV module is calculated by using the relation given by

$\beta opt = \tan^{-1}[\{\sum_{i=1}^{12} \bar{H}bi \tan|\phi - \delta i|\}/\{\sum_{i=1}^{12} \bar{H}bi\}]$ [3]

Where, $\bar{H}bi$ is daily average beam radiation on the horizontal surface, ϕ is the latitude of location, δ is the declination angle given by

$\delta=23.45 \sin\{(360/365)(284+n)\}$ [4]

Where, n is the number of day in a year which is taken as 105.

Moreover, the module was tilted facing due south and the reflecting mirrors were fixed at an angle given by

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$\Psi = \frac{(\pi - \beta - 2\phi + 2\delta)}{3}$ [5].

Thus, by using βopt, Ψ and δ we optimized the solar radiation intensity striking the PV panel surface with no need of sun tracking system. The actual experimental module is shown in Fig 2.

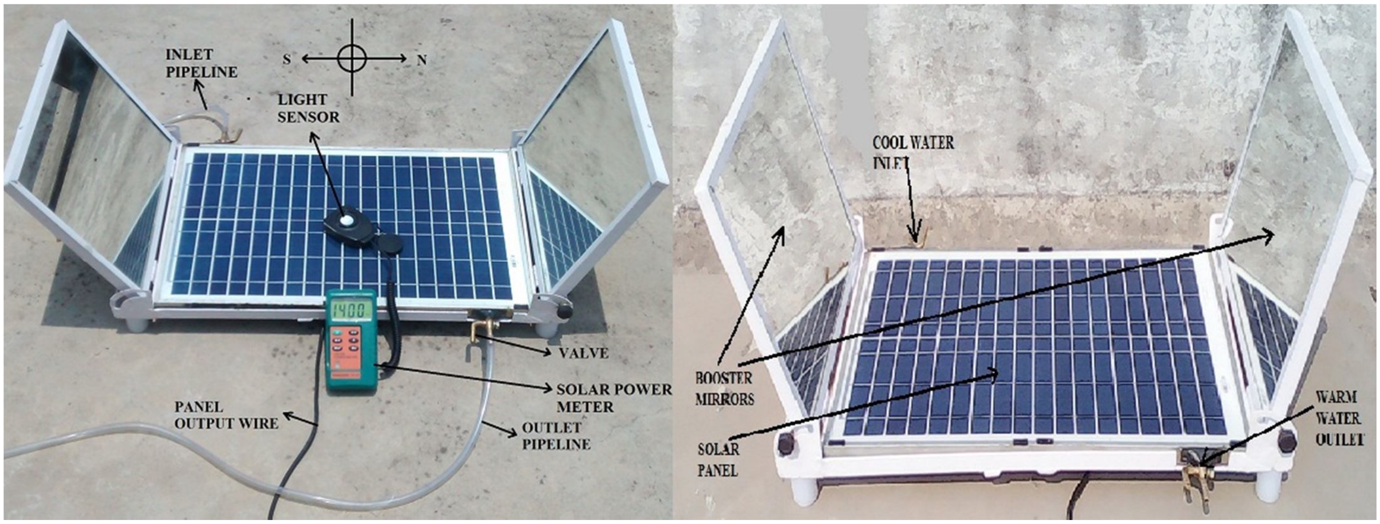


Fig 2. Actual Experimental Module.

III. EXPERIMENTAL PROCEDURE

Performance analysis of selected solar PV module when it is cooled by using submersible water pump as active cooling device is done by comparing the electrical output under cooled condition with uncooled condition. Also the performance of module in non-concentrated solar radiation with cooling is tested by comparing the electrical and thermal output with concentrated solar radiation with cooling. The performance of module is also tested under concentrated and cooling condition by using 3.5% Salt water as coolant.

A. Procedure for Condition 1

Under this condition the performance of PV module was tested directly by observing the electrical output with respect to solar radiation intensity. The electrical output was noted by observing the open circuit voltage (Voc) and short circuit current (Isc) which is displayed by two digital multi-meters separately. The intensity of incident radiation is directly measured by the solar power meter. The theoretical electrical efficiency is calculated and compared with experimental electrical efficiency. The temperature at the top surface of PV module and ambient temperature were also noted from the digital temperature indicator. Hourly readings were noted down with the changing solar incident angle from 9:00 hr:mm to 17:00 hr:mm.

B. Procedure for Condition 2

Under this condition the PV module is tested by observing the electrical and thermal output. The electrical output and electrical efficiency is calculated as that of in Condition 1. 12 V DC pump is used to circulate the cooling water from the tank to the PV module and then it returned in the same tank. The pump is powered by solar power and as the radiation intensity increased pump output was also increased. The Thermal output is calculated by observing the inlet and outlet temperature of cooling water from the digital temperature indicator. The sensor of temperature indicator was directly inserted into the pipe just before inlet and just after outlet of PV module. The fluid flow rate is measured in litre per sec and then converted into Kg/sec. The wind speed is noted down hourly with the help of Anemometer. Top surface temperature of PV module, ambient temperature was also noted from the digital temperature indicator. Very little hourly variation is observed in ambient temperature (Ta) and solar radiation intensity (G) when readings were compared with the readings of Condition 1. Thus, hourly variation of (Ta) and (G) is kept common for both Condition 1 and Condition 2. Theoretical and Experimental Thermal efficiency and Overall efficiency was calculated.

C. Procedure for Condition 3

Under this condition the role of reflecting mirrors came into play. The mirrors facing due south and north direction were fixed at an angle 50^0.The Theoretical and Experimental values of Electrical, Thermal and Overall efficiencies were calculated by following the same procedure in Condition 2.Due to concentration of solar radiation on the PV module surface the intensity of incident solar radiation (G) were found to be increased considerably but no change is observed in ambient temperature (Ta). Hourly solar radiation intensity readings were noted down from 9:00 hr:mm to 17:00 hr:mm.

D. Procedure for Condition 4

Under this condition Salt water of 3.5% concentration is used as coolant instead of normal water. Rest of the experimental procedure is same as for Condition 3.The intensity of concentrated solar radiation and wind speed for Condition 3 and Condition 4 is kept common due to very little hourly variations is observed.

IV. ASSUMPTIONS AND CALCULATIONS

A. Assumptions

For simplification of the calculations the following assumptions are made

1) Heat losses from the edges and the back of the PV panel are neglected.
2) The leakage of coolant from the PV panel is negligible.
3) An average wind speed for the whole day was used for estimation of the convection coefficient of PV panel.
4) The readings of solar irradiation and ambient temperature from the experiment were used as the input for theoretical calculations.
5) The readings of solar irradiation in Condition 1 and Condition 2 is constant.
6) The readings of solar irradiation in Condition 3 and Condition 4 is constant.
7) The fluid flow rate and ambient temperature in every hour of day is assumed to be same for all Conditions.

Calculation of PV Module temperature

For calculation of theoretical value of PV module temperature ($T_{pv.th}$)following relation is used.

$T_{pv.th} = T_a + (\{T_{NOCT} - 20\}/800)*G$ [6]

Where, T_{NOCT} is the nominal operating cell temperature.

$T_{NOCT} = 20^0C + T_{rise}$ [7]

T_{rise} is the the ambient air temperature at the sunrise time.

Calculation of Electrical Power:

For calculation of experimental value of Electrical power ($P_{max.exp}$) following relation is used.

$P_{max.exp} = FF \cdot V_{oc} \cdot I_{sc}$

Where, FF is the Fill factor (value given by manufacturer).

V_{oc} & I_{sc} are Open Circuit Voltage and Short Circuit Current measured by Digital multi-meter respectively.

Calculation of Electrical Efficiency:

For calculation of experimental electrical efficiency ($\eta_{ele.exp}$) following relation is used.

$\eta_{ele.exp} = \frac{P\ max.exp}{G\ .\ Aabs}$

Calculation of Heat Extracted by coolant:

For calculation of experimental value of heat extracted by coolant ($Q_{c.exp}$) following relation is used.

$Q_{c.exp} = m \cdot C_p \cdot (T_{fo} - T_{fi})$

Where, m is mass flow rate of fluid in Kg/sec

C_p is the specific heat capacity of fluid.

T_{fo} & T_{fi} are fluid outlet & fluid inlet temperature from the PV module respectively.

Calculation of Thermal efficiency:

For calculation of experimental value of Thermal efficiency ($\eta_{thermal.exp}$) following relation is used.

$\eta_{thermal.exp} = Q_{c.exp}/(G \cdot A_{abs})$

Calculation of Overall efficiency:

For calculation of experimental value of Overall efficiency ($\eta_{overall.exp}$) following relation is used.

$\eta_{overall.exp} = Q_{c.exp} + P_{max.exp} / (G \cdot A_{abs})$ [8]

V. RESULTS AND DISCUSSIONS

Experimental data is tabulated of the performance of solar PV module under Conditions 1, 2, 3 and 4 and different graphs were plotted of Time against different parameters to conclude the experimental results.

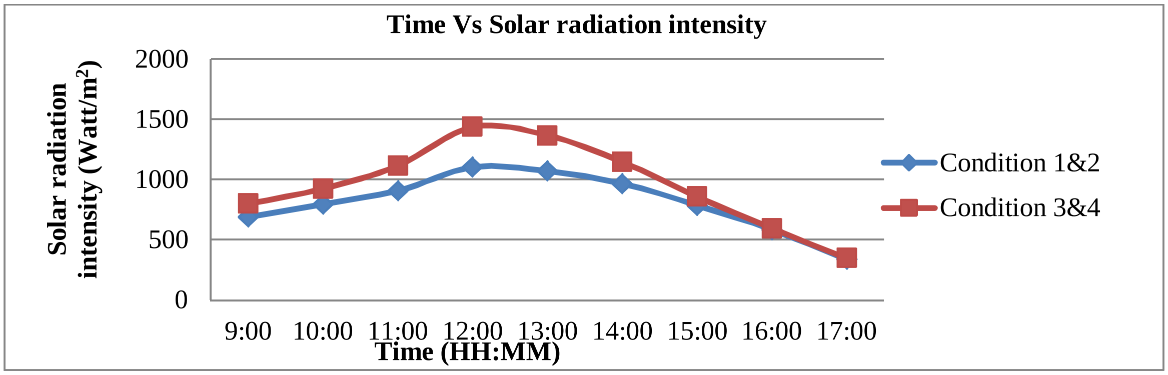


Fig 3.Hourly variation of Solar radiation intensity for Condition 1&2 and Condition 3&4.

From Fig 3**.** When solar radiation was not concentrated on PV module surface in Condition 1&2 their intensity is observed having highest value 1105 Watt/m^2 and when the radiation was concentrated using reflecting mirrors on PV module the Solar radiation intensity is increased and its maximum intensity reached 1440 Watt/m^2. Hence, due to our concentrated system the average solar radiation intensity over the whole day increased by 18.6%.

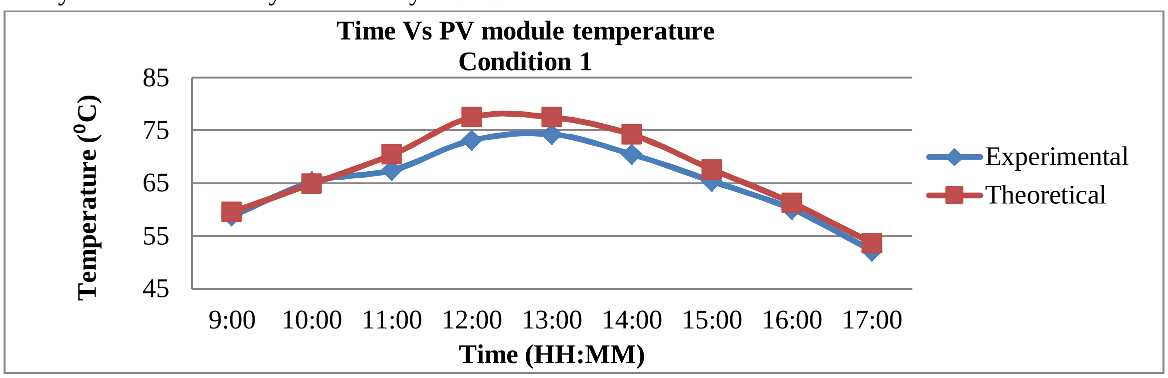


Fig 4. Hourly variation of PV module temperature for Condition 1.

Fig 4. shows that for Condition 1 the experimental PV module temperature varies nearly the equal to the theoretical value. The difference in average experimental and theoretical values over the whole day is 2.17^{0}C. This difference is of 3.2%.

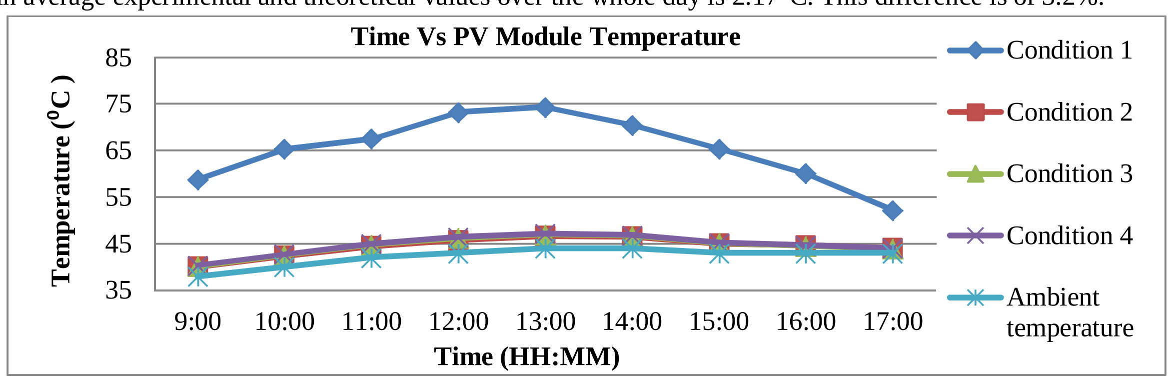


Fig 5. Hourly variation of PV module temperature for all Conditions.

Fig 5. shows that when we performed active cooling of PV module its temperature dropped considerably and maintained nearly equal to the Nominal operating cell temperature (NOCT) ie., 45^{0}C for Condition 2,3 and 4. The PV module temperature is found to be slightly higher than ambient temperature.

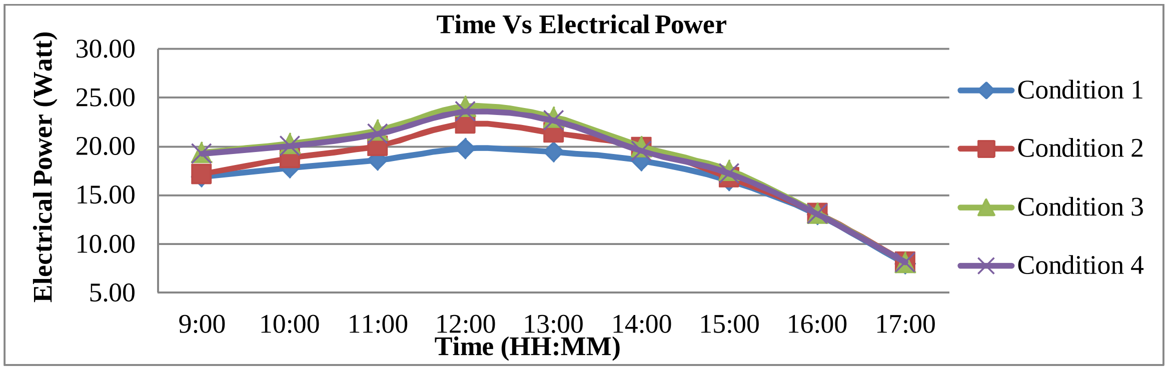


Fig 6.Hourly variation of Electrical Power for all Conditions.

Fig 6. shows that the electrical power output from Condition 3 is maximum while it is minimum from Condition 1.The electrical power output from Condition 4 is more than that from Condition 1 and Condition 2, but slightly less than that from Condition 3. Thus, Condition 3 and Condition 4 both can be effective to maximise power output than Condition 2.

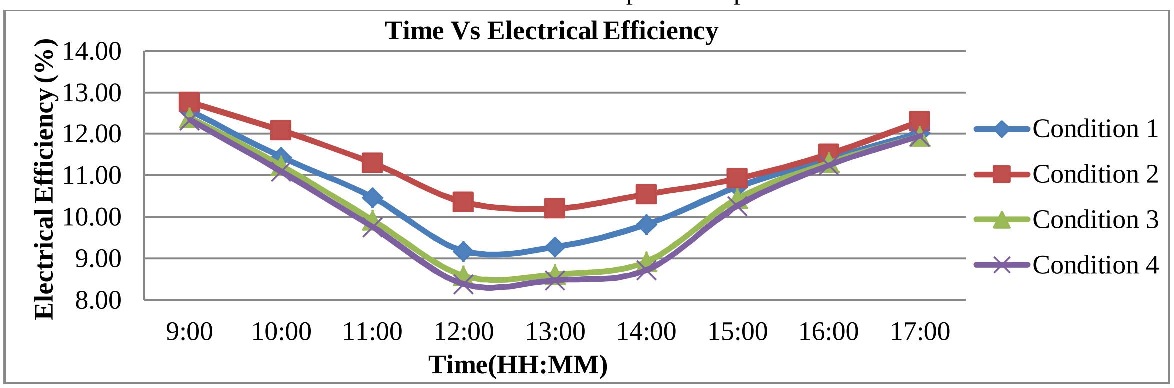


Fig 7.Hourly variation of Electrical Power for all Conditions.

Fig 7. shows that the electrical efficiency of Condition 2 is maximum while it is minimum of Condition 4.The electrical efficiency of Condition 3 is less than that of Condition 1, but slightly more than that from Condition 4. Thus, in Condition 3 and Condition 4 the electrical efficiency drops considerably due to high concentration of solar radiation on the PV module surface.

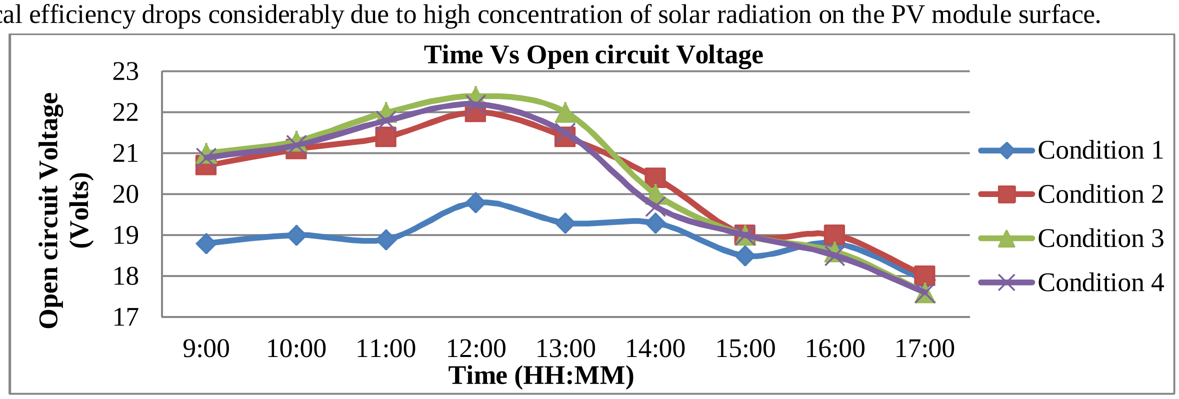


Fig 8.Hourly variation of Open circuit Voltage for all Conditions.

Fig 8. shows that Open circuit voltage is maximum for Condition 3 and minimum for Condition1. For Condition 2 and Condition 4 variation in open circuit voltage is similar, it is higher for Condition 4 till 13:00 hours and then it is higher for Condition 2 till 17:00 hours for the day. Thus, when we started cooling of PV module in Condition 2, Condition 3 and Condition 4 considerable increase in open circuit voltage of solar PV module observed.

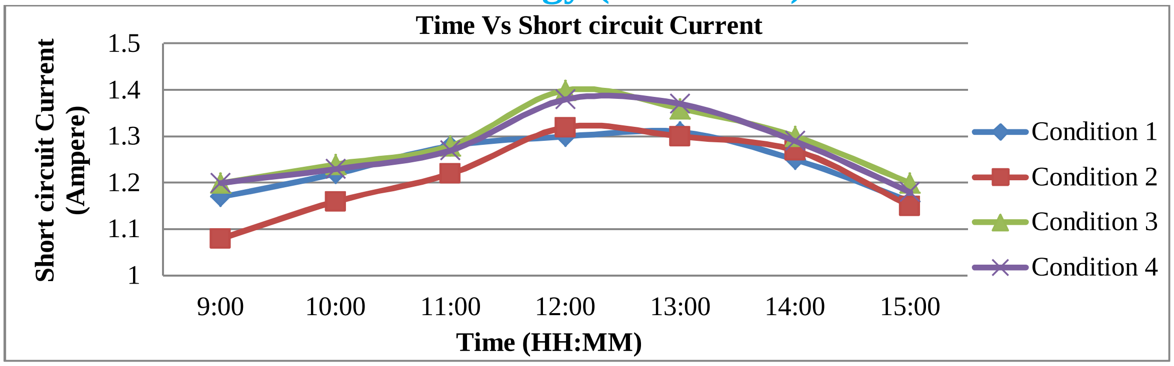


Fig 9.Hourly variation of Short circuit current for all Conditions.

Fig 9. shows that Short circuit current is maximum in Condition 3and minimum in Condition 2. Thus, concentration of solar radiation in Condition 3 and Condition 4 resulted in increase of short circuit current.

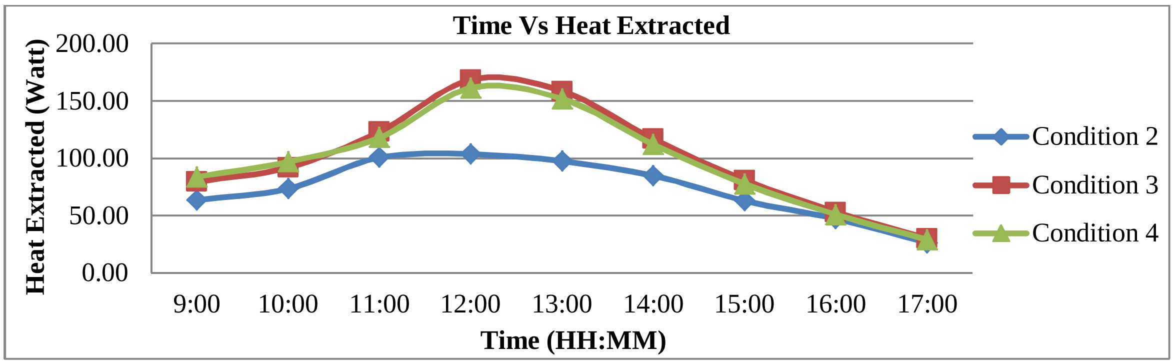


Fig 10. Hourly variation of Heat extracted for all Conditions.

Fig 10. shows that the heat extracted in Condition 3 is maximum while it is minimum in Condition 2.The heat extracted in Condition 4 is slightly less than that in Condition 3, but more than that in Condition 2. Thus, in Condition 3 and Condition 4 the heat extracted by the cooling fluid considerably increases due to high concentration of solar radiation on the PV module surface and active cooling.

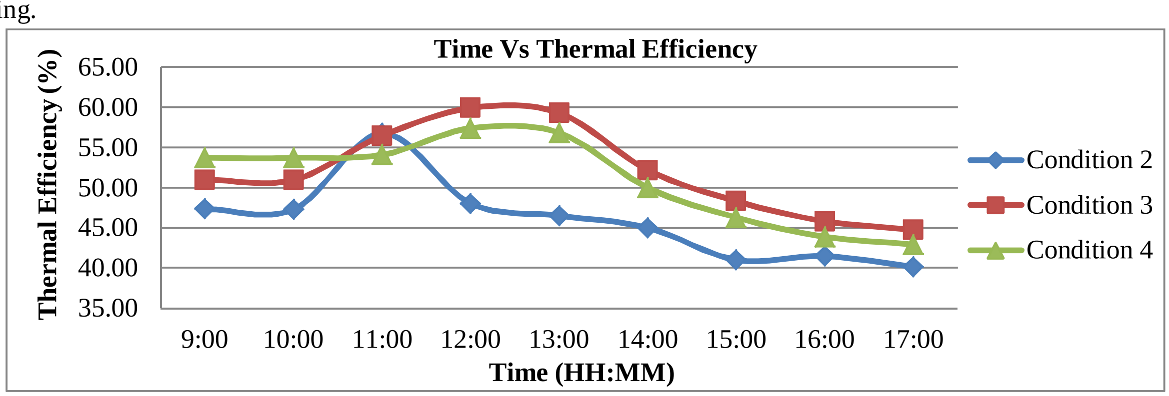


Fig 11.Hourly variation of Thermal Efficiency for all Conditions.

Fig 11. shows that the Thermal Efficiency in Condition 3 is maximum while it is minimum in Condition 2.The Thermal Efficiency in Condition 4 is slightly less than that in Condition 3, but more than that in Condition 2. Thus, in Condition 3 and Condition 4 the Thermal Efficiency considerably increases due to high concentration of solar radiation on the PV module surface and active cooling.

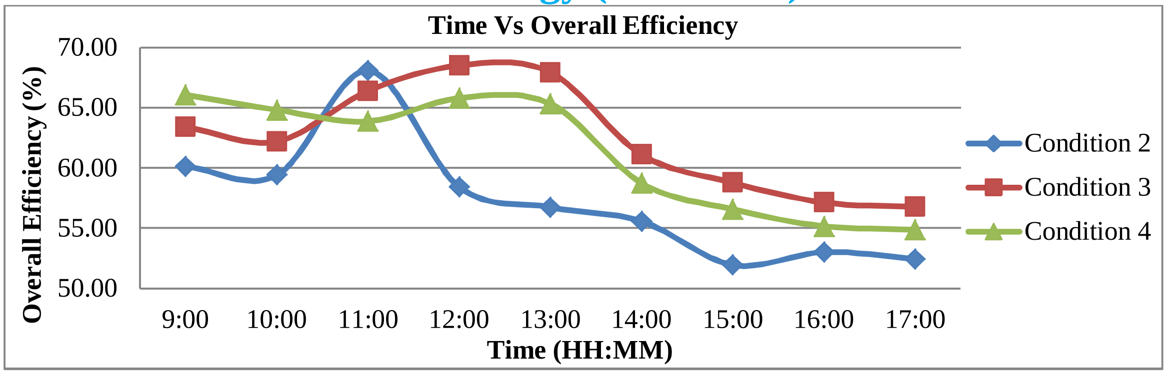


Fig 12.Hourly variation of Overall Efficiency for all Conditions.

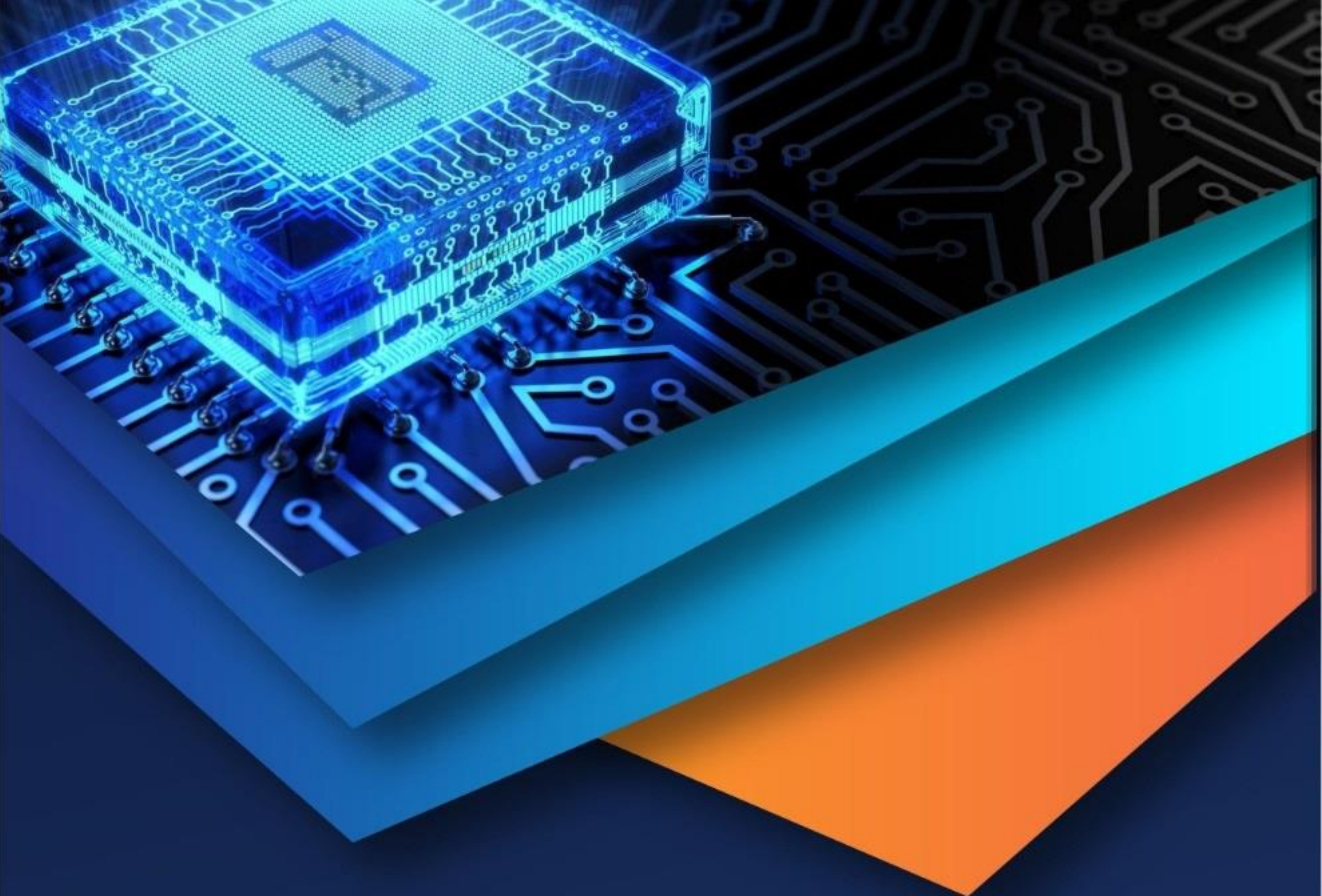
Fig 12. shows that the Overall Efficiency in Condition 3 is maximum while it is minimum in Condition 2.The Overall Efficiency in Condition 4 is slightly less than that in Condition 3, but more than that in Condition 2. Thus, in Condition 3 and Condition 4 the Overall Efficiency considerably increases due to high concentration of solar radiation on the PV module surface and active cooling. The improvement in average overall efficiency in Condition 3 than Condition 2 is 5.2%. Thus, Total 9% overall efficiency improved in Condition 3 than Condition 2.

VI. CONCLUSIONS

After experimental results it can be concluded that when solar radiations are concentrated on the surface of PV module the heat extracted by cooling water is maximum. Thus, even though we have concentrated solar radiations on PV module surface its temperature did not increase, kept towards lower side. When performance of PV module is tested using different coolant such as normal water and salt water of 3.5% concentration and it is found that normal water as coolant gives slightly better performance of PV panel than salt water. It is also concluded that when solar radiation was not concentrated on the solar PV panel and cooled the maximum electrical efficiency is obtained but electrical power output was lower than it was under concentrated system of radiation. The concentrated radiation condition gives electrical efficiency lower than that of uncooled PV panel but electrical power output was maximum when water as coolant was used and radiations were concentrated. The maximum thermal efficiency and overall efficiency is obtained when solar radiation was concentrated on solar PV module and cooled by normal water, while it is slightly lower when salt water (3.5%) is used as coolant. Thus, both the mechanisms are effective as required.

REFERENCES

[1] Wikipedia article “Sea water”, which has been released under the GNU Free Documentation License.
[2] K. T. Patil, ‘Feasibility Investigations and Performance Analysis of Non Concentrated Solar Photovoltaic Thermal System for Nagpur’. International Journal of Engineering Research & Technology IJERTV4IS050979 Vol. 4 Issue 05, May-2015.
[3] Kern, J., and Harris, I. 1975. On the optimum tilt of a solar collector, Solar Energy, 17:97.
[4] A data book on Thermal Engineering, Green Brains Publications, Page (78).
[5] Solar energy principles of thermal collections and storage (Third Edition), by S.P.Sukhatme, J.K.nayak, Chapter: Concentrating Collector (page no. 205).
[6] Review 6 (1) (2013) 87 -90. Alonso Garcia MC, Balenzategui JL. Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculation. Renew Energy 2004;29:1997–2010.
[7] Bharti R, Kuitche J, Tamizh-Mani G. Nominal operating cell temperature (NOCT) effects of module size, power, load and solar spectrum. In: 34th IEEE photovoltaic specialists conference (PVSC), Arizona State University, USA, 7–12 June, 2009. p.1657–62.
[8] Master’s Thesis on ‘Photovoltaic Thermal (PV/T) System: Effect of Active Cooling’ by TEO HAN GUAN – http://scholarbank.nus.edu.sg/handle/10635/17723.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY