Numerical and Experimental Investigation on PV Panel with Phase Change Material

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Abstract- A part of solar radiation incident on Photo Voltaic (PV) panel is converted into heat energy. Since the rise in temperature of PV panel has a negative effect on efficiency, several cooling methods were proposed by researchers so far. PV panel with Phase Changing Material (PCM) provides maximum power by reducing the operating temperature of the panel. The efficiency of PV panel can be further improved by increasing thermal conductivity of PCM by using thermal conductivity enhancer. In the present work Aluminium is used as the thermal conductivity enhancer and paraffin wax as PCM and the numerical analysis gives the optimum height of the thermal conductivity enhancer. Results of the CFD analysis is implemented in the fabrication of PV-PCM experimental set up. The PV module without PCM had a temperature of 59 °C and with PCM have a temperature of 54°C, so the PV Panel temperature reduction is 5°C at the peak time, which reduces the negative effect on efficiency. PV module cooled with PCM showed better efficiency than without PCM and it increases the efficiency from 9.71% to 10.38% at the peak time of solar intensity. The experimental results have been compared with numerical results in hand and is found to be matching well and is also compared with the experimental results in the literature for the same range(850W/m^{2})of irradiation but for a different PCM material and are found to be matching qualitatively well with a higher efficiency for the present work.

Keywords: PV panel, Phase Changing Material, Thermal Conductivity Enhancers.

1. INTRODUCTION

Renewable energy sources have become so-important as there are significant benefits. Among all the renewable sources, solar energy, photovoltaic in particular, is a very effective solution for renewable energy. The amount of solar energy incident on earth surface is approximately 1.5×10^{18} kWh/year, [2] which is about 10000 times the current annual energy consumption of the entire world. The solar power could also be utilized in two ways

- By collecting the radiant heat and using it during a thermal system.
- By collecting and converting it on to electricity employing a solar photovoltaic system.

Photovoltaic solar energy is a clean, renewable source of energy that uses solar radiation to produce electricity **.**Nowadays, the PV system is recognized and widely using in electric power applications.

One of the main problems that face the operation of the PV panel is very low PV cell conversion electrical efficiency. This is also a main difficulty of scientists and researchers to enhance the electrical efficiency of PV cells. The power output yield by the PV system mainly depends on the following factors

(i) Solar radiation

(ii) Operating temperature of PV panel

The appropriate cooling of the P.V. array tends to reduce the loss of output and increases the reliability of the P.V. module. Passive cooling and active methods of cooling are employed to improve performance of P·V. modules. Active cooling requires a coolant, like air or water, which typically involves fan or pump power, whereas passive cooling requires no special power to cool P.V. cells. Increased power output through active cooling will offset power consumption is an important economic factor.

Passive cooling techniques are classified into three main categories: passive cooling of the air, passive cooling of water and conductive cooling. Passive cooling might include extra components, like heat pipe or sink to drive natural convection cooling. They are placed at the bottom of the solar panel to maintain the overall transfer of heat from the panel to the local environment.

Moharram et al. [1] carried out experiment for enhancing the performance of photovoltaic panels by water spraying. When the temperature of PV panel reached maximum allowable temperature of 45℃ the temperature sensor runs the motor resulting in water spraying on PV module and cools the PV cell to normal operating temperature of 35℃. They could observed that PV panels yielded the very best output energy by cooling the PV panels to the normal operating temperature.

Teo et al. [2] developed an active cooling system for photovoltaic modules. A parallel array of ducts with inlet and outlet manifolds designed for uniform air flow distribution was attached to the rear of PV module. The experiment was carried out with and without active cooling. Without active cooling, the temperature of the module was high and photovoltaic cell achieved an efficiency of 8-9%. For the PV module operated under active cooling condition, the temperature of the module dropped significantly and solar cell achieved efficiency of 12-14%.

Swapril et al.[3] performed a study to evaluate the performance of PV module by back surface water cooling in hot climatic condition. Both numerical and experimental studies were performed for the climate of Saudi Arabia and the result showed a good agreement between them. With the active cooling technique, the operating temperature of module dropped significantly to about 20% and an increase of 9% in the electrical efficiency was observed.

Prakash et al. [4] carried out experiment to regulate the temperature of photovoltaic modules to improve energy yield, by the use of a heat exchanger with water as the working fluid. The heat exchanger was attached to the back side of PV module and had a single pass heat exchanger system. The module operating temperature was reduced by 18-20^{o}C and resulted in increased power output by nearly 10%.

Rok Stropnik et al. [5] studied the effect of phase change material (PCM: OM-29) on the electrical efficiency and power output of photovoltaic (PV) panel. The results showed that the generated electrical power output increased by 4.3 to 8.7% and energy generation efficiency increased by 0.5 to 1%, compared to the conventional PV module.

Kumaresan et al. [6] focused on the effect of operating temperature of the solar photovoltaic (PV) module on conversion efficiency. The rise in operating temperature of the solar photovoltaic (PV) module led to loss of conversion efficiency.

Adeel Waqasa et al. [7] analyzed the effect of Phase Change Material (PCM: RT-37) on electrical efficiency and operating temperature of PV panel.

PCM was filled in rotatable shutters attached to the back side of PV panel. Efficiency could be improved up to 9% for the PV panel working under hot humid climatic conditions.

Present work focuses on the numerical and experimental investigation on the effect of phase change material on the performance of PV panel. Considering the melting point, cost and availability of OM-44 (paraffinwax) is chosen as the phase material. For further enhancement in heat transfer Aluminium is used as the container material and within which the PCM is placed.

2. NUMERICAL AND EXPERIMENTAL ANALYSIS

A. *Numerical Analysis*

The present work is to regulate the temperature of the PV panel and increase its efficiency. The PV panel with phase change material (PCM) provides maximum power by reducing the operating temperature of the panel. The efficiency of PV panel can be further improved by increasing thermal conductivity of PCM by using thermal conductivity enhancer. In the present work aluminium is using as the thermal conductivity enhancer and the CFD analysis is used to obtain the optimum height of the thermal conductivity enhancer.

After creation of the geometric model the next step is meshing. The total mesh count was found to be 9552 elements and 10020 nodes from grid independent study.

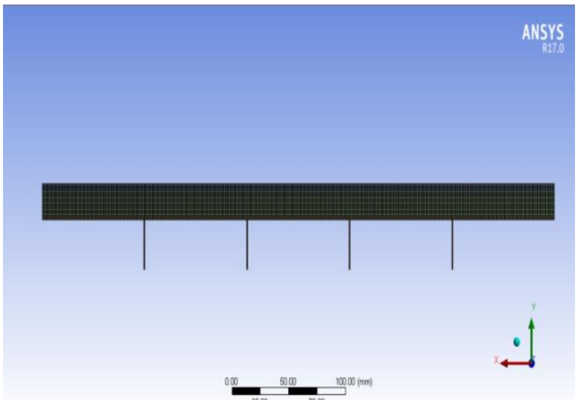

Fig. 1 Meshing of the computational domain

Numerical analysis of the PV-PCM system has been done in this work. Simulation results for different heights of PCM containers are presented in the form of various contours and graphs and the optimum PCM container height is selected for fabrication process.

The temperature contour of PV-PCM system with PCM container height 10mm is shown in Fig 2. The average temperature obtained for PV panel top side is around 329.6 K and at the PCM container is around 320.3 K.

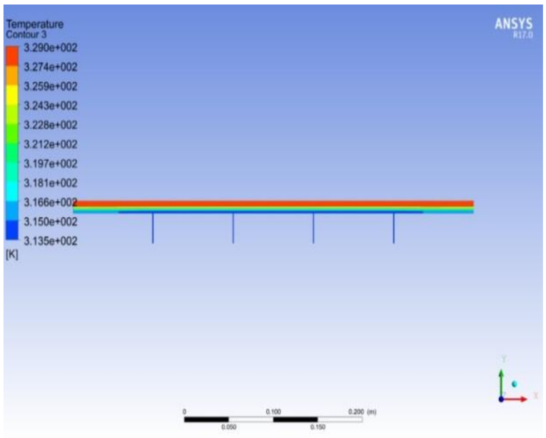

Fig 2 Temperature contour of PV-PCM system with PCM container height 10mm

If the temperature increases at the top side PCM absorbs heat and changes its state from solid to liquid. The melting point of PCM is 42^{o}C and during evening this PCM releases stored heat to the PV panel and thereby increases efficiency.

Numerical analysis of the PV-PCM system has been performed using ANSYS software for varying PCM container heights. PCM container height that gives minimum panel temperature is chosen as the optimum value and is selected for fabrication. The chosen value is 10mm.

B. *Experimental Analysis*

Active test period is specified from 10.00 am to 4 pm, in which solar intensity increases first and then decreases. Solar intensity is measured by using lux meter. Different temperatures (i.e., Panel temperature, PCM temperature and ambient temperature) are measured by calibrated K type thermocouple. The current and voltage are measured by multimeter.

Fig 3 Fabricated container filled with PCM

C. *Experimental Setup*

Fig.4 Experimental Setup

The experimental setup (Fig.4) consists of two PV Panels, lux meter, data logger, K type thermocouples and Multi meter. Both panels are of same rating and size. The rating of PV Panels is 12V and 20W. Panels are manufactured by LOOM SOLAR Private Limited. The size of the panel is about 450mm×350mm×25mm. One panel is conventional panel and rear side of other panel is filled with PCM in aluminium container with dimension430mm×330mm×10mm. The thickness of the aluminium container is 1mm. The two panels are placed on the stand side by side in such a way that the solar radiation incident on both the panel is almost same. The stand is inclined at an angle of 45° throughout the experiment and the direction of stand is changed with respect to the sun's direction in such a way that the radiation incident on solar panel will be high.

D. *Performance Parameters of Solar Panel*

1. Efficiency of the solar panel

Sun's irradiance falls on the solar panel and gets converted into electrical energy. Thus solar power conversion efficiency is defined as ratio of product of maximum voltage and current to the product of amount of solar irradiance and area of the panel. Efficiency of panel in %

- Efficiency of panel= $\frac{V_m I_m}{EA}$ ×100…..….[1]

Solar panel efficiency depends on maximum power output, which indirectly depends on the temperature of the panel

- Maximum power output

  $P_{max} = V_m \times I_m$ (W)…………………….[2]
- Ideal power output $P_o = V_{oc} \times I_{sc}$ (W)…..[3]

where

V_m= maximum output voltage (v)

I_m=maximum output current (amp)

V_{oc}=open circuit voltage (v)

I_{sc}=short circuit current (amp)

2. Fill factor

It is the ratio of maximum power P_{max} to the ideal power. Fill factor (FF) is mainly controlled by V_{oc} which decreases with the increase in temperature [5].

- Fill factor FF = $\frac{V_m I_m}{V_{oc} I_{sc}}$…………………[4]

The maximum power produced by the solar panel is calculated from the values of total output voltage and current from the solar panel as follows. Unit of power 'Watt'

➢ $P_{max} = V_m \times I_m = FF \times V_{oc} I_{sc}$ ....[5]

3. Normalized power output efficiency

The normalized power output efficiency (η_p) is the ratio of the output power measured under actual conditions and that under the standard condition. Normalized power output efficiency in %

Normalized power output efficiency=$\frac{P_{actual}}{P_{stc}} \times 100$

3. RESULT AND DISCUSSIONS

Experiments have been conducted on the PV panels under different climatic conditions and from the measured variables like voltage, current, temperature etc. the performance parameters have been calculated and are plotted against different parameters.

A. Experimentation on conventional and modified PV panels

Experiments have been conducted on both conventional and modified PV panels for PCM passive cooling. Conventional and modified PV Panels were compared and investigated. Measured values are recorded during the period 10.00 am–4.00 pm where the solar irradiance was almost constant at high values. The preliminary results are shown in below.

Fig 5 shows the variation of solar radiation intensity with time. The maximum intensity is 920W/m^2 at the time of 12.30pm and minimum solar intensity is 570W/m^2 occurred at the time of 4pm.

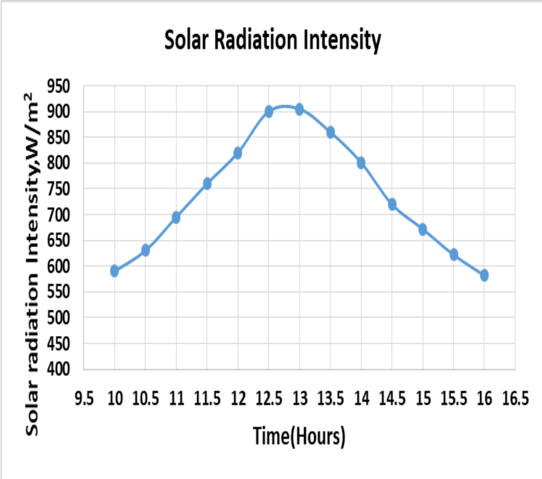

Fig 5 solar irradiation

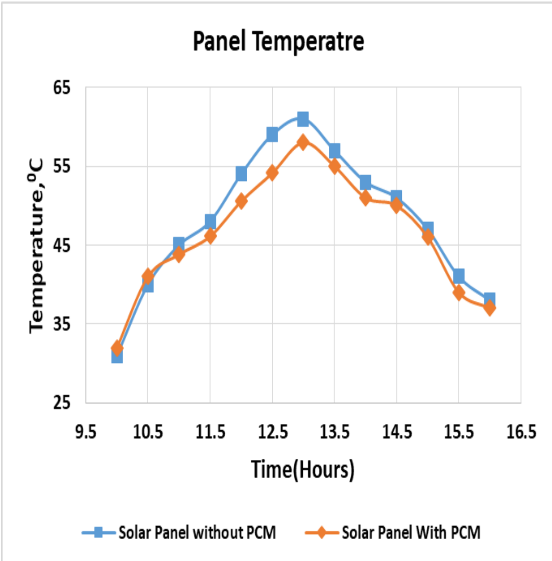

Fig 6 PV Panel temperature

The temperatures of the PV modules, with and without PCM, were monitored and are plotted against time as shown in Fig.6. The module without PCM had a maximum temperature of 59 °C and the ambient temperature during the test was 29–37 °C with an average of 33.9 °C. Thus, when cooling the module with PCM (OM44) in the back side of the modified PV-PCM system, the heat was absorbed by the paraffin wax to change it from solid to liquid phase. Since the melting point of paraffin wax (OM44) is 42-47 °C, it can be said that heat transfer was mostly in the form of latent heat. The PV module with PCM had temperature of 54°C and the PV Panel temperature reduction is 5°C.

B. Electrical Power Output

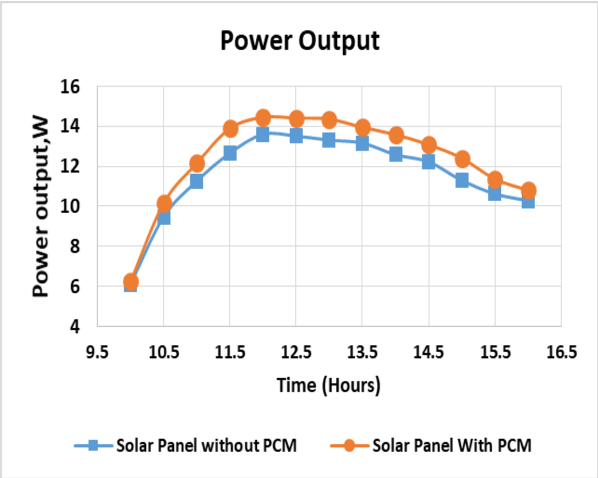

Fig 7 PV Panel Power output

Experimental data during the period 10.00 am to 4.00 pm for PV modules with and without PCM were investigated. The electrical output power and solar irradiation were recorded for 2 days and averaged. The results are plotted in Fig7, where the variation of output power was due to the varying level of irradiance during the day. It was obvious that the PV module cooled by PCM container produced higher power for all the irradiance.

The maximum difference in power output between the PV module with and without PCM was observed. Around 2W increases in power output were noted while using phase change material (PCM). Also the maximum power output is 14.82W at the time of 12pm. The minimum power output is 6.5W and is around10am.

C. PV Module Efficiency

The data reduction in terms of the module efficiency was done and is depicted in Fig.8. The averaged module efficiencies changed according to the irradiance during the tested days.

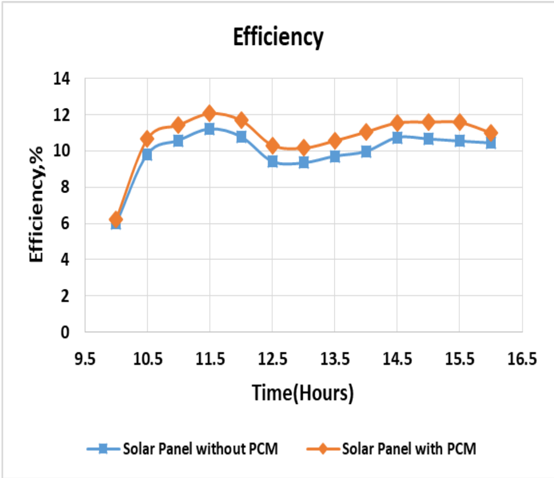

Fig 8 PV module efficiency

As expected, the PV module cooled with PCM box showed better efficiencies than without PCM and the efficiency raised from 9.71% to 10.38%, equivalent to a 5.8% improvement at the peak time.

Also in the above results 8% improvement in efficiency is obtaining at 2.30pm and 11.30am, the maximum efficiency is obtained at the time of irradiance is 750 W/m^2 .The results also showed that the PV surface temperatures were reduced while using PCM cooling, causing higher efficiency. In addition, it was found that the efficiency could be insignificantly improved when the irradiance was less than 620W/m^2.

D. Validation of Numerical And Experimental Analysis

Fig 9 shows the variation of Numerical and Experimental values of panel temperature with respect to the solar intensity. This graph proves that Numerical and Experimental values of PV panel temperature obtained are almost same. The PCM absorb the heat from the panel and reduced the panel temperature and increasing the performance of PV Panel.

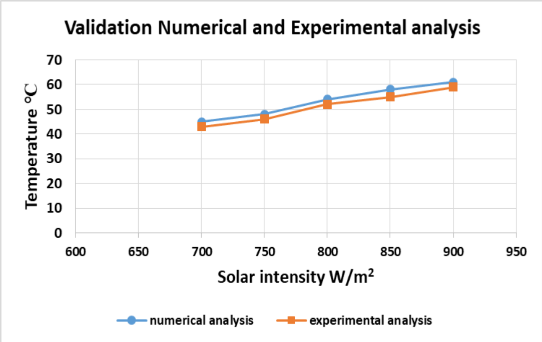

Fig 9 Validation of Numerical and Experimental Analysis

E. Validation of PV Panel Efficiency From Journal

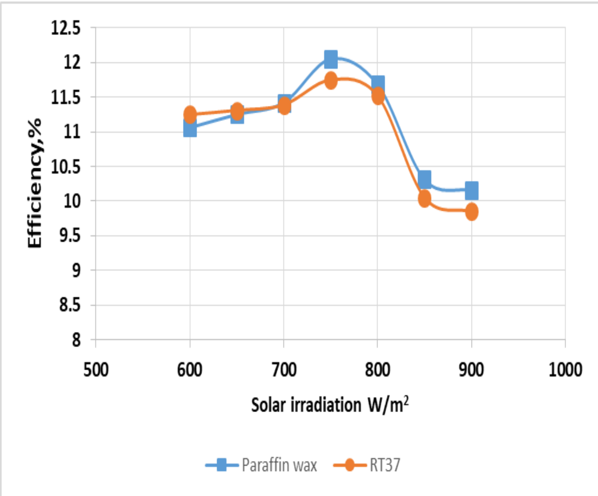

Fig 10 PV panel Efficiency validation from journal

Present work has been compared with the work done by Sudhakar *et al* .[6] . They have used RT 37 as phase change material instead of paraffin wax (OM44) in the present work . In addition to that they have used glass cover as the container material instead of Aluminium in the present case. The efficiency obtained for the same range of irradiation are qualitatively matching with the present work with a noticeably higher efficiency for the present work. So paraffin wax(OM44) as the phase change material with Aluminium as the container material is recommended with the PV panel to improve their performance.

4. CONCLUSION

Present work was focusing on the numerical and experimental investigation on the performance of PV panel with and without PCM. Numerical analysis was carried out in order to select the height of aluminium container for storing PCM that maximizes heat transfer and thereby minimizes panel temperature. Photovoltaic panel was fabricated with and without PCM. Following conclusions have been drawn from the experimental and numerical investigations performed.

- ➢ Efficiency of the system found to be increasing with decreasing surface temperature
- ➢ The experiments have been conducted from 10AM to 4PM and the maximum temperature observed was 59 °C in the PV module without PCM and 54°C in the PV module with PCM (paraffin wax) and so the PV Panel temperature reduction is 5°C at the peak time 12.30PM and at irradiance of 905 W/m^2.
- ➢ By implementing phase change material (PCM) inside PV panel around 2W increases in power output were noted.
- ➢ PV module cooled with PCM box showed better efficiencies than without PCM cooling and the efficiency increases from 9.71% to 10.38%.
- ➢ Compared the experimental and numerical values of PV panel temperature and the variation are almost same with respect to intensity of radiation.
- ➢ So recommended to incorporate PCM (paraffin wax) in the PV panel so as to enhance its performance

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