SMART COOLING SYSTEM FOR SOLAR PHOTOVOLTAIC MODULE

Chandrashekar S[2], Sandeep K[1], Javul Mulla[2], Bharath D[2], Raghavendra R[2]

[1]Assistant Professor, Department of Mechatronics, Acharya Institute of Technology, Bengaluru,
[2]Bachelor of Engineering, Department of Mechatronics, Acharya Institute of Technology, Bangaluru-107, India.

***Abstract*:** Photovoltaic (PV) modules have the capacity to generate electricity when solar radiation is incident on them. But this incident radiation causes an increase in temperature of PV module which results in decrease in its efficiency. This adverse effect invites a necessity to cool the module. In this project, an efficient way has been designed by introducing a smart cooling system consisting of a heat exchanger which helps in extracting the heat generated by the PV module and thus increases its efficiency.
The cooling system used is a combination of active and passive cooling methods. Aluminium alloy 6063 is used as a heatsink material along with the PCM which is fixed to the back side of the PV panel. Here we use a combination of paraffin wax and bee wax as phase changing material (PCM). Smart Cooling system is used to cool both the heatsink and PV module. Experiment will be carried out with the comparison of normal PV module and PV module with Smart cooling system.
Various performance parameter such as current, voltage and power are obtained, the values obtained are compared with a normal PV module. It was found that the PV module with PCM integrated system was more efficient compared to normal PV module. ANASYS CFD analysis shows that the adopted smart cooling system will maintain the PV module with in the required temperature for more efficient performance.

Keywords: Smart cooling system, Solar PV panels with aluminium sheets (6063), Phase Change Material (Paraffin wax and bee wax), Conventional refrigeration system, Solar monitoring and controlling.

I. INTRODUCTION

Energy is very important in today's world. It is necessary and a basic need to all living creature and life. Energy is the quantitative property that must be transferred to an object in order to perform work. We use various types of energy resources to produce electricity which we need in day to day life such as we need for our homes, schools, businesses, and industries. There are two types of energy resources are available, one is renewable energy, and other one is Non-renewable energy. Majority of the energy is derived from fossil fuels, such as coal, natural gas, and petroleum, these all are Non-Renewable sources. Renewable sources of energy can be used often times. Renewable resources comprise of solar energy, wind energy, geothermal energy, biomass and hydropower. The sun is the main and basic source of all the energy available on earth. Among all the renewable energy, solar energy is a best effective solution for utilizing in available renewable energy. Solar power has necessarily become the trend in renewable energy. The most known fact about solar energy is that it represents a clean, safe and green source of energy**.** Basically, solar energy is an energy that comes from the sun which is converted into electricity. To convert solar radiation into electricity we use a solar photovoltaic cell. A solar photovoltaic cell is made of semiconductor material which absorbs photons in solar rays and converts into Direct-Current (DC). About 80 to 85% of solar radiation is converted into electricity by PV panel and 15% to 20% is wasted as heat. Hence increase in PV panel temperature and so decrease in its efficiency. One of the significant issues in the photovoltaic business is solar panel efficiency enhancement, which is reached by its temperature. Therefore, introducing efficient cooling methods with extricate heat from PV panels must be taken into consideration. Until now, many researchers have been completed to lessen the PV panel temperature. A system to increase the electrical efficiency of solar cell by cooling the cell with the help of various heat sinks and wick structure with copper and aluminium fins, and then the heat removed from the back surface of the panel with the help of fins that absorb heat generated by the cells during the day. Therefore, the decreased temperature of PV panel increases the electrical efficiency of solar cell [6]. The recommended procedures for PV panel cooling are arranged into active and passive strategies [1]. In the active techniques, extra energy is required to cool the PV panel. Nevertheless, no energy is required for passive cases. No compelling reason to include power makes the passive cooling techniques progressively mainstream. In our experiment, an efficient way has been designed by introducing a smart cooling system consisting of heat exchanger which helps in extracting the heat generated by the PV module and thus increases its efficiency. The cooling system is used as a combination of both active and passive cooling methods. Aluminium alloy 6063 is used as a heat sink material [2] along with the Phase changing material [3], which is fixed to the back side of the PV module. Smart Cooling system is used to cool both the heat sink and PV module. Experiment will be carried out with the comparison of normal PV module and PV module with Smart cooling system.

II. FACTOR AFFECTING SOLAR PHOTOVOLTAIC EFFICIENCY

One of the main obstacles that is faced by the operation of the PV panel is very low PV cell conversion to electrical efficiency. This is also a key obstacle of scientists and researchers to enhance the electrical efficiency of PV cells. The power output by the PV system depends on factors such as operating temperature of PV module, shading and radiation.

III. OBJECTIVE

The objective of the present work is to design a smart cooling system for cooling the solar cell in order to increase its electrical efficiency and also to extract the heat energy.

IV. PROBLEM DEFINITION

PV modules have the capacity to generate electricity when solar radiation is incident on them. But this incident radiation causes an increase in temperature of PV module which results in decrease in its efficiency. This adverse effect invites a necessity to cool the module.

V. EXPERIMENTAL SETUP

The description of the experimental setup is presented. The experimental set up is designed to investigate the effect of addition of water circulation and phase change material, to survey the effect of temperature on the efficiency of the PV panel. The schematic layout and the 3D model of the designed system are presented in Fig 2. The PV panel is a poly-crystalline silicon PV panel with a maximum power of 40 Watt. The PV panel has an area of 2866.1499 cm^2. The Open-circuit voltage (V_{oc}) and Short-circuit current (I_{sc}) of the panel are 22.3694 V and 2.1995 A, respectively. A passageway for water flow is created behind the module between two aluminium sheets attached.

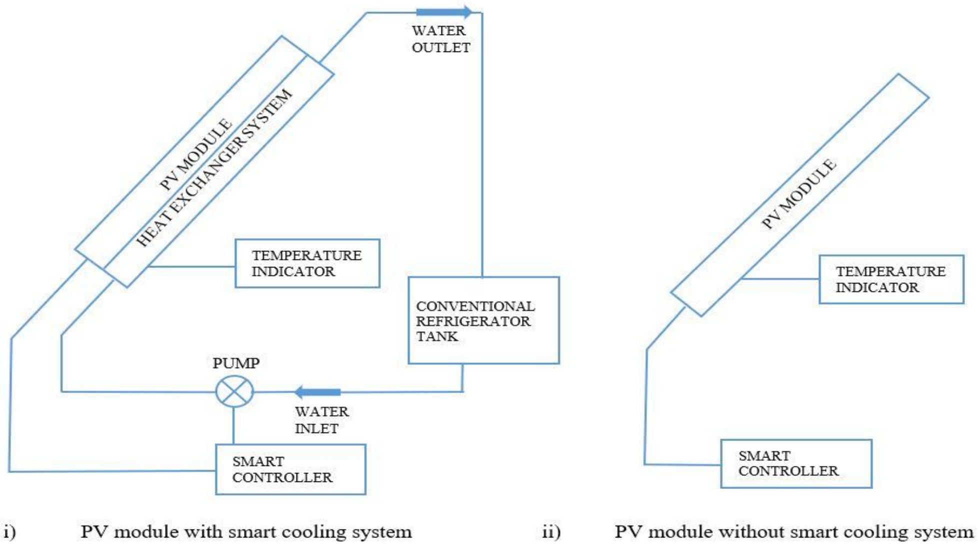


Figure 1: Experimental system.

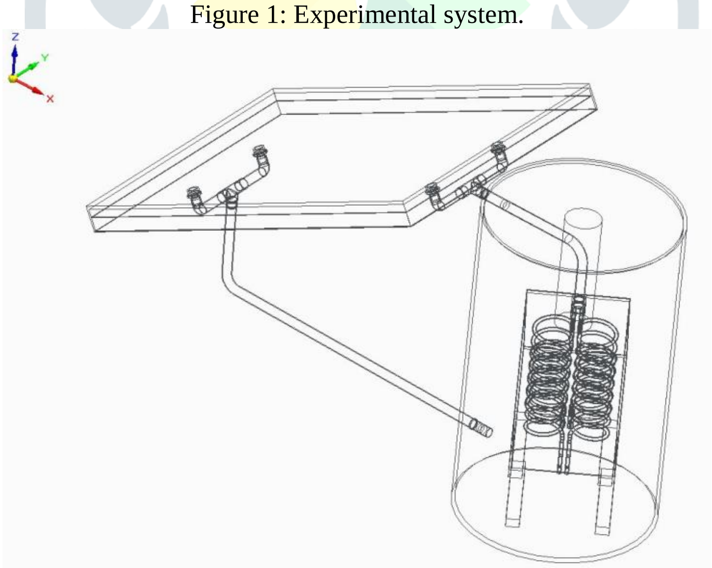


Figure 2: 3D Model of Smart cooling system.

The water is stored in a tank with a conventional refrigeration system. This system helps to keep the water temperature within the required limit so that the long-term cooling is available using same fluid. Conventional refrigeration system consists of 4x of copper wire twisted and placed in an aluminium box. PCM is covered between these copper pipe (⌀ 6mm) and aluminium box (volume 4725 cm^3). The schematic 3D model of conventional refrigeration system is presented in the Fig.3.

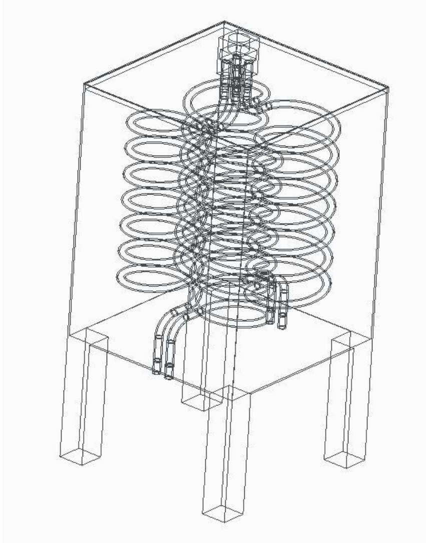


Figure 3: Conventional refrigeration system

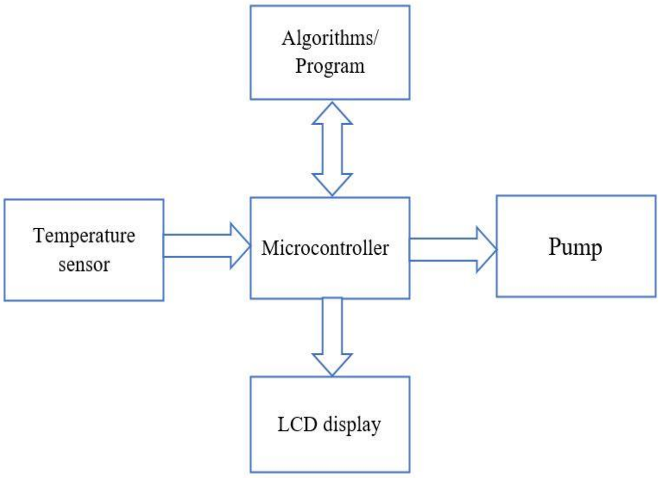


Figure 4: Control module

The solar PV module monitoring and controlling activity of the system is done by a single microcontroller (AT mega 328P). The schematic block diagram of the control module is represented in the Figure 4.

- The basic concept is to maintain a constant temperature of the Solar PV Panel (i.e. within 30˚C-35˚C).
- Aluminium alloy and PCM material will works as Heat Exchangers which is attached to the back of the PV panel [5][7].
- Temperature sensor is used to monitor the temperature of the PV panel.
- Temperature sensor sends temperature data to microcontroller, where microcontroller analyzes the temperature data according to algorithm provided and controls the turning on/off of the pump to reduce the temperature.
- Water used as coolant fluid helps to maintain the constant temperature of the PV module.
- Temperature, voltage, and current will be displayed in the LCD using temperature sensor, voltage sensor and current sensor respectively.
- +5V to +7V supply is required to turn on the microcontroller, which is supplied externally.

CFD ideal fluid flow analysis:
CFD analysis with the aid of ANSYS CFD-Fluent is performed to visualize the ideal scenario of convection heat transfer between ideal fluid (water) and surface of PV module. By ideal modelling methods and laminar water flow parameter, the simulation is conducted to observe heat transfer between solid surface of PV module compressed of aluminium alloy 6063 and water. Since the ideal case is assumed, the boundary layer is expected to be laminar with the solid-fluid interface between the inner walls and ideal fluid. Furthermore, the initial temperature condition of outer wall is assumed to be 30˚C.

VI. COMPONENTS USED

1. **PV Module:** These photovoltaic panels absorb sunlight as a source of energy to generate direct current. A photovoltaic (PV) module is a packaged, connected assembly of photovoltaic solar cells available in different voltages and wattages. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications.

Table 1: Solar panel specification.

PARTICULARS	
Ambient Temperature	25˚ C
Make	Loom Solar
Model area (cm^2)	2866.1499
Current (I_{mp})	2.1137
Voltage (V_{mp})	19.2813
Short circuit current (I_{sc})	2.1995
Voltage open circuit (V_{oc})	22.3694
Power (P_{mp})	40.7547

2. **PCM Material:** Paraffin wax and bee wax is a phase changing material (PCM) [4]. Mixture of paraffin wax (70%) and bee wax (30%) is used in PCM. Due to less melting point of paraffin wax bee wax is mixed with it. Melting temperature of paraffin wax is 44˚C with Thermal conductivity 0.2 W/m-K. Bee wax has a melting point range of 62-64˚C.
3. **Aluminium Alloy:** The most common heat sink materials are aluminium alloys. Aluminium alloy of 6063 grade has Tensile strength of 145-186 MPa, Specific heat capacity of 900 J/kg-K and Thermal conductivity of 201-218 W/m-K.
4. **Temperature Sensor:** A temperature sensor is a device that measures the temperature data from a particular source and converts the input data into electronic data form. DS18B20 temperature sensor and LM35 temperature sensor are used. DS18B20 temperature sensor has a range 0-125˚C and LM35 temperature sensor with range of -55˚C-150˚C.
5. **Coolant Fluid (Water):** The most common coolant is water. Water has high heat capacity which makes it a suitable heat-transfer medium.

6. **Microcontroller (AT mega 328P):** A microcontroller is a compact integrated circuit designed to govern a specific operation in an embedded system. A typical microcontroller includes a processor, memory and input/output (I/O) peripherals on a single chip. This can easily be used to actively monitor solar PV temperature and perform operation to maintain the efficiency.
7. **Pump:** It is a small device used to move liquid. In our case pump is actuated when the temperature rises in PV modules and moves cooling fluid to eliminate temperature in it to increase efficiency.

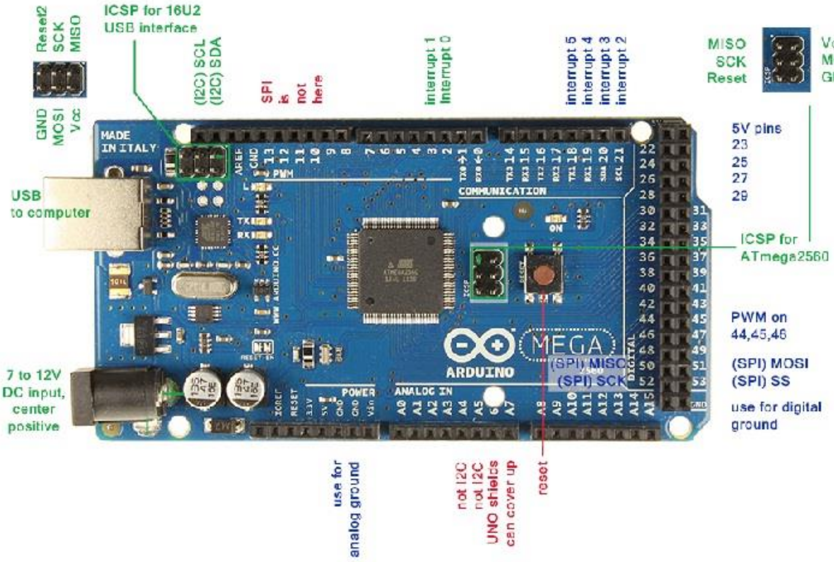


Figure 5: Arduino AT mega 328P.

VII. RESULTS AND DISCUSSION

a. **Experimental Result:** An experiment was conducted on 22/07/2020 from 7:55AM to 1:00 PM (12.994°N, 77.508°E) and recorded various parameters such as voltage, current, and temperature for PV panels of both Smart cooling system (PCM integrated) and normal system tabulated in the Table 2.

Table 2: Recorded parameters on 22/07/2020.

Time	Atms T Avg	Normal System					PCM Integrated System					PCM P	P
		T1	T2	T Avg	V	I	T1	T2	PCM T Avg	V	I		
7:57:01	24.25	28.81	26.37	27.59	20.48	0.99	25.9	26.5	26.17	20.65	1.1	22.42	20.1
8:09:01	21.22	26.41	24.99	25.7	20.66	1.18	25.1	25.1	25.09	20.84	1.2	25	24.4
8:19:00	20.71	26.81	25.34	26.07	20.95	1.2	25.3	25	25.14	21.04	1.23	25.88	25.1
8:29:01	20.27	27.34	26.22	26.78	21.09	1.23	25.9	25.4	25.62	21.14	1.25	26.43	25.9
8:40:00	22.8	28.99	27.43	28.21	21.06	1.23	26.4	26.3	26.34	21.13	1.26	26.62	25.9
8:59:01	23.72	31.57	30.55	31.06	20.82	1.26	28.7	28.2	28.42	20.92	1.31	27.41	26.2
9:09:01	24.01	31.89	31.1	31.49	20.88	1.5	29.8	29.1	29.41	20.88	1.54	32.15	31.3
9:19:00	25.23	33.15	32.32	32.74	20.92	1.51	30.7	30.1	30.41	21.09	1.57	33.11	31.6
9:29:01	24.09	32.71	32.13	32.42	20.96	1.55	31.2	30.5	30.82	21.01	1.66	34.87	32.5
9:39:01	24.34	32.42	32.13	32.28	20.92	1.52	31.8	30.9	31.36	21	1.63	34.23	31.8
9:49:01	25.97	33.2	32.76	32.98	21.05	1.62	32.2	31.3	31.75	21.08	1.74	36.67	34.1
9:59:00	26.71	34.91	33.89	34.4	21.03	1.69	32.5	31.8	32.16	21.06	1.8	37.91	35.5
10:09:01	30.08	36.52	36.23	36.38	21.31	1.73	33.5	32.6	33.08	21.32	1.84	39.22	36.9
10:19:01	30.47	37.6	37.55	37.57	21.03	1.73	34.5	33.7	34.08	21.2	1.86	39.44	36.4
10:29:01	31.79	39.01	39.11	39.06	20.85	1.74	35.5	34.4	34.93	21.09	1.88	39.65	36.3
10:39:01	31.55	39.16	39.55	39.36	20.63	1.71	36.4	34.8	35.6	21.14	1.87	39.54	35.3
10:49:01	32.43	39.16	38.87	39.01	20.52	1.72	37	35.6	36.29	20.82	1.89	39.35	35.3
10:59:01	31.75	41.11	39.94	40.53	20.64	1.65	37.3	36.1	36.68	20.56	1.79	36.81	34.1
11:09:01	32.77	39.65	39.65	39.65	20.88	1.6	38.3	36.6	37.43	20.91	1.76	36.81	33.4
11:19:01	31.74	40.48	41.84	41.16	20.51	1.64	39	36.2	37.59	20.59	1.83	37.67	33.6
11:29:01	34.33	42.38	43.75	43.07	20.72	1.78	39.6	37.1	38.37	20.73	1.9	39.39	36.9
11:39:01	35.84	43.55	45.17	44.36	20.64	1.72	40.6	37.8	39.16	20.69	1.85	38.27	35.5
11:49:01	34.67	42.38	44.19	43.29	20.49	1.74	40.8	38	39.39	20.57	1.88	38.67	35.7

11:59:01	35.01	40.48	44.24	42.36	20.56	1.78	41.7	38.4	40.04	20.73	1.9	39.38	36.6
12:09:01	35.69	40.68	45.31	42.99	20.56	1.7	41.8	38.6	40.16	20.67	1.82	37.61	35
12:19:00	36.67	42.78	46.88	44.83	20.55	1.68	42.5	39	40.78	20.62	1.75	36.08	34.5
12:29:01	38.18	44.34	46.73	45.53	20.52	1.63	42.3	39.4	40.83	20.58	1.75	36.02	33.5
12:39:01	37.64	42.04	47.22	44.63	20.47	1.68	43.1	39.8	41.42	20.62	1.83	37.73	34.4
12:49:00	38.04	43.56	47.61	45.58	20.25	1.77	43.2	39.9	41.52	20.56	1.91	39.27	35.8
12:59:01	37.68	44.24	47.75	46	19.97	1.71	43.7	40.3	42.03	20.49	1.82	37.28	34.1

Where, Atms T = Outer Temperature, T = Temperature, V = Voltage, I = Current, P = Power.

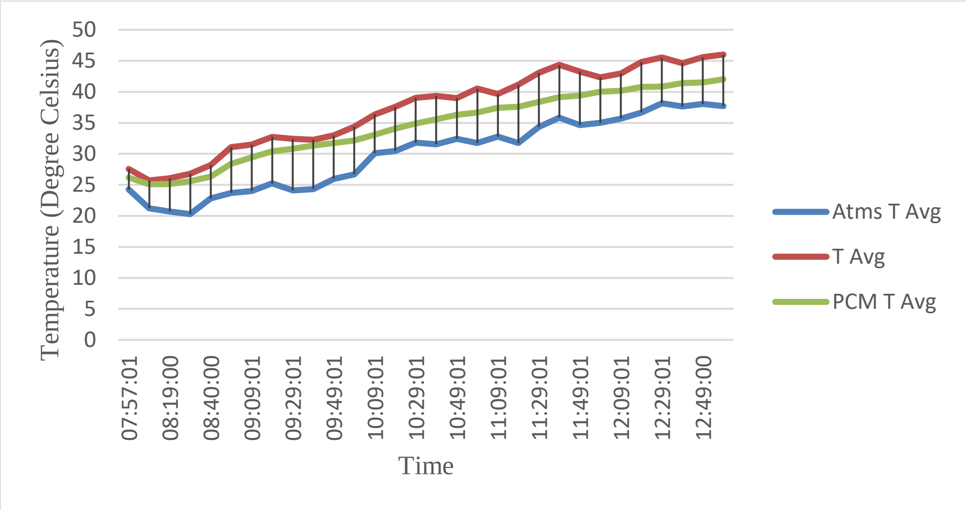


Figure 6: Comparison of temperature between PV module having PCM, normal system and outer temperature.

Figure 6 shows a graph for variation of temperature versus time for PCM integrated system (grey color), normal system (red color) and outer temperature (blue color). It can be observed from the graph that PV module with PCM is moderately cooler than normal PV module.

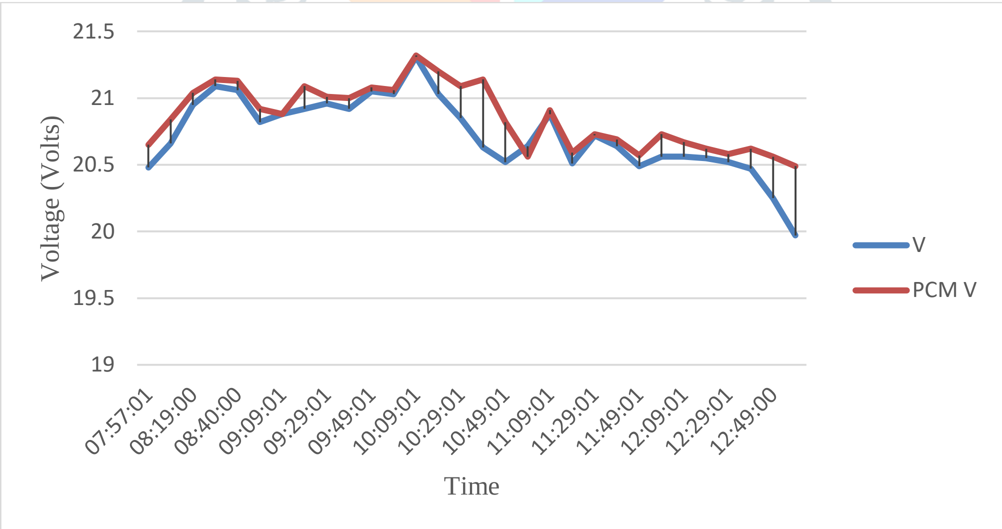


Figure 7: Comparison of voltage between PV module having PCM and normal system.

Figure 7 shows a graph for variation of voltage versus time of the PV panels of both PCM integrated system (red color) and normal system (blue color). It can be observed from the graph that voltage is directly proportional to the incident radiation and the PV module with PCM integrated system generates relatively more voltage than the normal system.

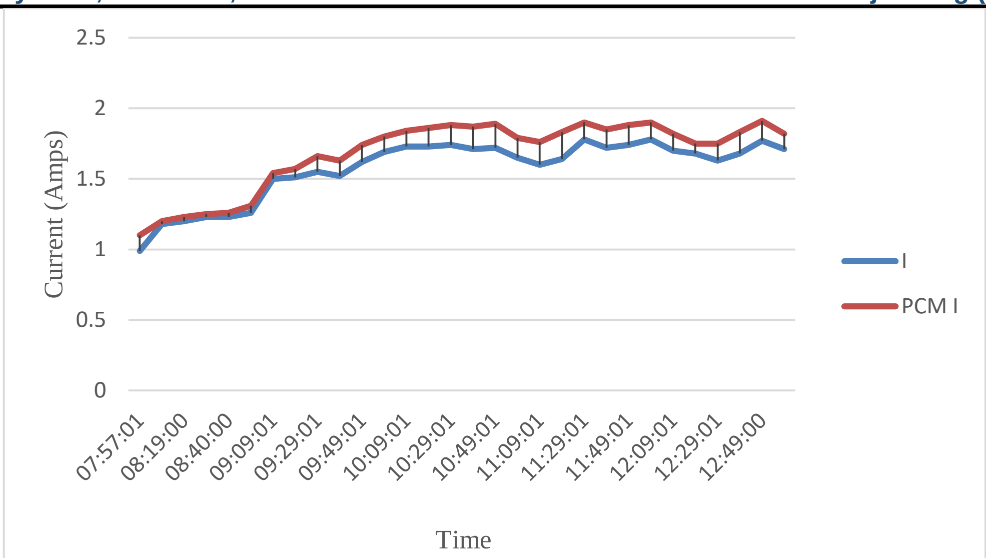


Figure 8: Comparison of current between PV module having PCM and normal system.

Figure 8 shows a graph for variation of current versus time of the PV panels of both PCM integrated system (red color) and normal system (blue color). It can be observed from the graph that current is directly proportional to the incident radiation and the PV module with PCM integrated system generates relatively more current than the normal system.

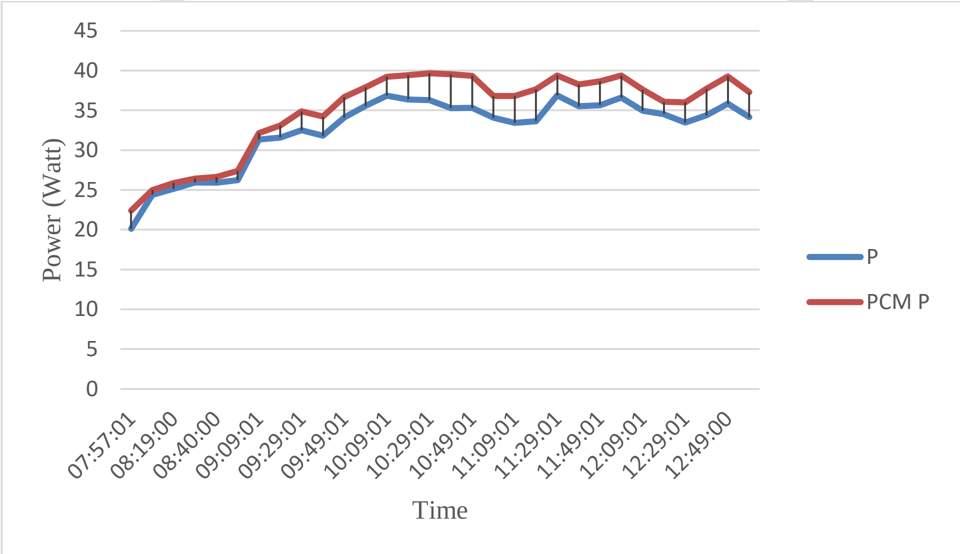
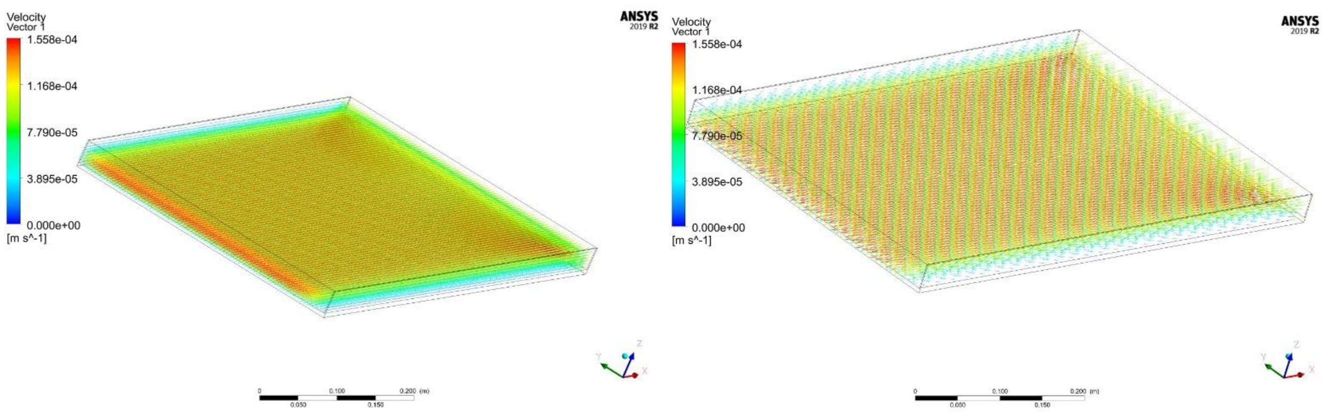


Figure 9: Comparison of power between PV module having PCM and normal system.

Figure 9 shows a graph for variation of power generated versus time of the PV panels of both PCM integrated system (red color) and normal system (blue color). It can be observed from the graph that power generated gradually increases with respect to time. Variation of power generation occurs due to incident radiation because power is a product of current and voltage. It can be observed that PV module with PCM integrated system generates relatively more power than the normal system.

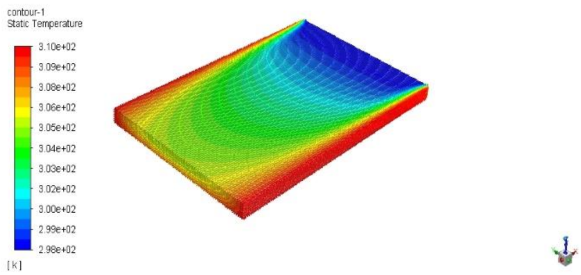
b. **CFD ideal fluid flow analysis:** Considering an ideal case of fluid flow, boundary layer streamline velocity with two different ideal fluid temperature (i.e., 18˚C and 25˚C) is observed to be 1.558e-01 m/s and maximum streamline velocity is at the surface contact between the ideal fluid and aluminium alloy 6063 is 7.790e-05 m/s, which is a laminar boundary layer. The maximum and minimum velocity vector are as shown in Figure 10.a and 10.b.



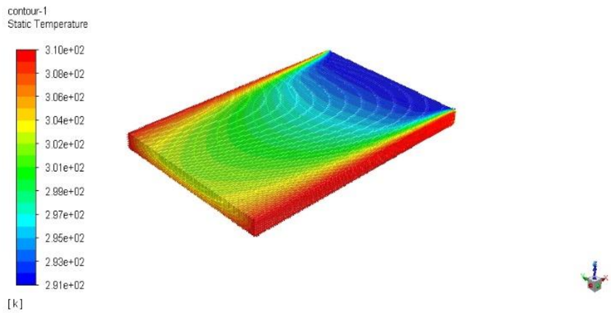
a: ideal fluid with 18˚C as inlet temperature. b: ideal fluid with 25˚C as inlet temperature.

Figure 10: ANSYS CFD-fluent visualisation of maximum and minimum velocity vector with laminar boundary layer.

Supporting visuals of surface temperature of a PV module after CFD ideal fluid flow analysis are displayed in the Figure 11.



a: ideal fluid with 25˚C as inlet temperature.



b: ideal fluid with 18˚C as inlet temperature.

Figure 11: ANSYS CFD-fluent visualisation of maximum and minimum surface temperature.

VIII CONCLUSION

Based on the experimental result, the effect of temperature on the PV module are studied and following conclusion can be made.

- By adopting the smart cooling system to the PV module, the temperature of the module decreases, therefore it increases the power and efficiency compared to normal PV module without the smart cooling system.
- In the above one day (22/07/2020) experiment it is found that PV module with Smart cooling system (PCM integrated) was 7.31% more efficient than the normal system.

Based on the CFD ideal fluid flow analysis, results are found that convection heat transfers occur between the Aluminium surface attached to PV module and ideal fluid (water). Keeping two different water inlet condition (i.e., 18˚C and 25˚C) the results shows that it helps to cool the surface of the PV module for more efficient performance of the PV module.

REFERENCE

[1] J. Sieckera, K. Kusakanaa, B.P. Numbi. A review of solar photovoltaic systems cooling technologies. Renewable and Sustainable Energy Reviews, 79 (2017) 192–203.
[2] M.Irwanto, W.Z.Leow , Y.M.Irwan, A.R.Amelia and I.Safwati ,Photovoltaic Module Performance Analysis of Aluminum and Zinc Thin Metal Sheet Attached With Direct Current Brushless Fans Cooling System, ISSN 0973-4562 Volume 12, Number 24 (2017) pp. 14130-14135.
[3] S.A. Nadaa,b,⁎, D.H. El-Nagarb, H.M.S. Hussein, Improving the thermal regulation and efficiency enhancement of PCMIntegrated PV modules using nano particles, Energy Conversion and Management 166 (2018) 735–743.
[4] R Thaib*1, S Rizal1, M Riza2, T M I Mahlia3, T A Rizal, Beeswax as phase change material to improve solar panel’s performance, Materials Science and Engineering 308 (2018) 012024.
[5] Stropnik, Rok & Stritih, Uroš. (2016). Increasing the efficiency of PV panel with the use of PCM. Renewable Energy.Volume97. Pages 671–679. 10.1016/j.renene.2016.06.011.
[6] Parkunam N, Lakshmanan Pandiyan, Navaneethakrishnan G, Arul S & Vijayan V, Experimental analysis on passive cooling of flat photovoltaic panel with heat sink and wick structure, Published on 14 Mar 2019.
[7] S.A. Nadaa D.H. El-Nagarb, H.M.S. Hussei, Improving the thermal regulation and efficiency enhancement of PCM Integrated PV modules using nano particles.