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DEVELOPMENT OF SINGLE AXIS SOLAR (PV) TRACKER AND ITS THERMAL ANALYSIS

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ABSTRACT
This research investigates the intricacies of 'Design, Development and Thermal Analysis of Single Axis Solar (PV) Tracker' and its pivotal in solar energy applications. The paper provides an overviews of the design parameters, structure, types, and drive system. In recent studies, two types of solar tracking systems have been discussed, namely a single axis solar tracking system and dual axis solar tracking system. We have addressed the parameters related to single axis solar tracker only by making use of MPPT. This study involves the use of SolidWorks, and IoT analytics platform to design and fabricate experimental model. The research also validates the experimental data (temperature) of photovoltaic panel with ANSYS Workbench R15 Simulation software. The maximum temperature recorded by experimental setup is 54.1°C and ANSYS solar panel simulation temperature is 55.97°C, which is temperature of 1.87°C higher as compared to experimental setup. As per comparison of experimental data and ANSYS simulation result we found, maximum 6.96% increases in the simulation result.

Keywords: LDR, MPPT, Solidworks, IoT, ANSYS Workbench R15.

INTRODUCTION
Solar energy is a huge, nonpolluting, and inexhaustible source of energy that is generated by harnessing the power of sunlight. It deserves a lot of attention due to decreasing the amount of fossil fuels. The earth received about 1.8 x 10^{11} MW of solar power, which could be 1,000 times the current consumption of all commercial energy sources on earth (K, 2011) [1].

The total installed grid connected power generation capacity around worldwide is more than 343899 MW as of May 2018. In which power generation mainly relies on coal and oil reserves accounting for a large production of about 67% while renewable energy from a large hydroelectric dam, biomass, solar and geothermal power contributes about 33% to the total world energy production.

Fig. 1 Solar Energy [2]

Solar radiation contains spectrum and infrared. The electromagnetic spectrum consists of three bands ultraviolet, visible, and infrared radiation. The wavelengths of ultraviolet light range from 100 nm to 400 nm. Infrared light has wavelengths between 700 nm to 1 mm, while visible light varies from 400 nm to 700 nm (Moghaieb, 2023) [15]. Wavelengths are used to measure solar radiation. PV cells utilize the photovoltaic effect to transform spectrum radiation into electricity. This effect involves the generation of voltage and electric current when any material is exposed to light. Consequently, solar PV cells absorb the spectrum radiation, converting it into usable electrical energy. A single solar panel integrates a substantial quantity of photovoltaic cells, and the cumulative current they produce combines to yield a sufficient amount of electricity.

LITERATURE REVIEW

In fact, (De Sá Campos, 2021) Manoel H. et. al. presented single axis solar tracker for n position to optimized solar energy. Their analysis led to the determination that their tracking system successfully attained an approximate theoretical efficiency of 99.27% [3]. Single axis solar tracker system designed by Aprillia et. al. (Rinaldi, 2020) as an open loop configuration. They concentrated on developing a single-axis open loop solar tracker system for photovoltaic panel, using a mobile app as a tracking system. The average output power was up to 17.15 W [4]. In various weather circumstances, Kuttybay, N. et al. demonstrated an optimized single axis schedule sun tracker (Kuttybay, 2020) [5]. The researchers found that it outperformed in gloomy and rainy weather. An evaluation of solar tracking and their potential in solar power applications was done by Hafez A. Z. et al. (Hafez, 2018). They explained a comprehensive overview of the diverse designs and components employed in these tracking systems [6]. Chin, C. S., Babu. et. al. (Chin, 2011) explain the intelligent tracker system operates in various modes to offer adaptability for different weather conditions. Throughout the day, the photovoltaic (PV) panel automatically adjusts its position according to sun irradiance, while during the night, it enters into a sleep mode to optimized power consumption [7]. Tudorache, Kreindler, et. al. (Tudorache) designed a solar tracker based on a dc motor as a driving mechanism that uses LDRs sensor to optimized the rotation of PV panel [8]. Asmarashid Ponniran et. al. (Ponniran, 2011) designed a single axis solar tracker that deliver a low speed and high rated torque, with little consequence of dc motor speed [9]. Ghazanfar Mehdi et. at. design tracking and non-tracking single axis solar tracker for PV panel. He found the static system generated 829.6 Wh of solar energy whereas tracking system elevated solar energy of 1742.88 Wh (Mehdi, 2019) [10]. Suneetha Racharla et. at. proposed solar tracking system – A review (Racharla, 2017). They reviewed various types of solar trackers and found single axis solar tracking system proves more favorable than dual axis counterpart [11]. Emre Kiyak et. at. done the analysis of fuzzy logic and PID controller based solar tracker (Kiyak, 2016). They found system energy collection increased around 21.2% when fuzzy logic and PID-based controllers are used [12]. Zhang, Q., Yang, D et. al. preformed the analysis of static and dynamic forces for solar auto tracking system. They found maximum stress consistently remains below than allowable stress so that mechanism stiffness and its strength are fully meets the needs of the design parameter (Zhang, 2010) [13]. Pulungan, A. B. et. al. describes the design and testing parameters of single axis solar tracker with IoT. They found solar tracker generated power very efficiently in summer but in rainy season its efficiency decreases (Pulungan, 2020) [14].

The primary objective of the research is to predict the temperature distribution and thermal behavior of photovoltaic panel under different working conditions including wind speed, ambient temperature, and solar irradiance. This informative data can help to optimize the design, development and thermal analysis of single axis solar tracker and improve its overall efficiency. Further sections are arranged as follows: section 3 represents the design and fabrication of single axis solar tracker. Section 4 provides calculation of solar radiation on tilt surface of solar panel, section 5 describe the thermal analysis of solar (PV) panel, section 6 provides results, section 7 describe conclusion and section 8 references.

DESIGN AND FABRICATION OF EXPERIMENTAL SETUP

Design of Experimental Setup

An experimental setup is connected with controller and sensors to records temperature, and tilt angle generated by solar PV panel. A tracker model was designed using SolidWorks 2022. Figure below shows the 3D model of single axis solar (PV) tracker.

Fig. 2 3D Model of experimental setup

Fabrication of Experimental Setup

For the mechanical structure, uses aluminum bar to fabricate C shaped channel to hold entire weight of PV panel and its support structure, T shaped channel to support dc gear motor to provide angular motion to the PV panel. The hardware prototype is assembled of different electronics device such as microcontroller, light dependent registers, DC gear motor, MPU 6050 gyroscope module, DHT22 temperature sensor and mechanical structure used for the mechanical support.

For the software design, ESP 32 microcontroller is used for controlling, analyzing, and processing the signals received from sensors and controllers. It is connected to an IoT platform to store data. The algorithm is designed in ESP 32 Dev Module with upload speed of the setup is set to 115200.

The electronic components that are used in the fabrication of the experimental model are as follows.

- **LM 393 LDR Module:** The LM393 light dependent registers are used to detect the sunlight falling on it. There are 5 LDRs used in this research. Two sets of LDR are used for controlling the clockwise and counter clockwise rotation of solar panel and one LDR is positioned within a hollow pipe at the middle of the panel to optimized the position of sun very precisely. The LDR sensors energies high in presence of sunlight and it became stumpy in the absence of sunlight.
- **ESP32 Microcontroller:** It is a highly integrated system that is designed for embedded application. It processes the signals received from all sensors and controllers and send to IoT platform for further analysis.
- Geared Motor: It is a mechanical device used to rotate the solar (PV) panel as per sunlight strikes on light dependent resisters from east to west and vice versa.
- **Solar Photovoltaic Panel:** Photovoltaic cells of solar panel converts spectrum radiation into dc electricity, used to charge the storage battery. I have used monocrystalline solar panel because it offers higher efficiency as compared to polycrystalline solar panel. The open circuit voltage (Voc) is 21.6V and short circuit current (Isc) is 0.62A with maximum power generation capacity of PV panel is 10 W.
- **DHT 22 Temperature Sensor:** DHT22 is a low in cost digital temperature sensor. It is used to measure the solar panel surface temperature.
- **MPU 6050:** It is a micro electromechanical sensor, which has three axis accelerometer and three axis gyroscope. MPU 6050 gyroscope module is used to measure the tilt angle of PV panel.
- **MPPT Charge Controller:** It regulate the current and voltage supply originating from solar panel to the battery. It is operated by ESP 32 microcontroller to ensure the battery is not overcharged during the day and doesn’t reverse the power into the solar panel overnight and drain the battery (S. HIWALE, 2014) [17].

- **Single Channel Relay:** There are three relay module used in this project. One sets of relay module are computing with ESP32 microcontroller and LDR sensor to control the rotation of dc motor and other relay module is connected with battery and charge controller to break reverse supply voltage from battery.
- **Storage Battery:** Storage battery is a device connected to solar panel through a MPPT charge controller. It stores electricity and run the entire setup during the daytime, and it also provide as a backup power source during a low irradiance and night.
- **Solar Buck Converter:** It is a dc to dc converter that regulates high voltage coming from solar PV panel to a required low voltage to the battery very efficiently (S. HIWALE, 2014) [17].

Calculation of Solar Radiation on Tilt Surface of Solar Panel

Solar PV panel surface temperature is changed by the amount of sun light received. Therefore, I have taken experimental data of clear sky and sunny day for thermal analysis of PV panel. The following numerical method is used for the calculation of solar irradiance for the tilt surface of PV panel (K, 2011) (Muhamamad Ahsan, 2019) [1,16].

Calculation of Radiation on Horizontal Surface

The project setup is assembled with a slope of 29° (Karafil, 2016) [21], in an Andheri east (19.1179 °N 72.8631 °E), Mumbai, Maharashtra, India - 400069.

1) Solar declination (δ) [1,16]:

$$\delta = 23.45 \sin\left[\frac{(284+n)*360}{365}\right]$$

Where n is the day of the year.

2) Latitude of the station ($\emptyset$):

$\emptyset$ = 19.1179°N

3) The equation of time (ET):

$$ET = 229.18\ (0.000075 + 0.001868\ \cos\cos B - 0.032077\ \sin\sin B - 0.014615\ \cos\cos 2B - 0.04089\ )$$

(K, 2011) [1,16]

Where $B = \left(\frac{(n-1)*360}{365}\right)$

4) Solar time (ST):

$ST = LT + (ET) - [(4) \times (L_S - L_L)]$ (K, 2011)

5) Hour angle (ω) [16]:

$\omega = 15\ (LT-12)$

6) Zenith angle ($\cos\theta_z$):

$\cos\theta_z = \cos(\delta)\cos(\emptyset)\cos(\omega) + \sin(\delta)\sin(\emptyset)$

7) Hourly beam radiation (I_{bn})

The ASHRAE model gives an approach for computing solar radiation falling on horizontal solar (PV) surface [18-20].

$I_{bn} = A \exp(-B/\cos\theta_z)$

Hourly diffuse radiation (I_d) is calculated by [1]

$I_d = C\ I_{bn}$

Hourly global radiation (I_g) is calculated by [1]

$I_g = I_{bn} \cos\theta_z + I_d$

Calculation of radiation for collector tilt surface

1) The beam radiation factor (R_b):

$$R_b = \frac{(sinsin\ (\delta)\ \square\square\square sin\ (\emptyset - \beta) + cos(\delta) coscos\ (\omega)\ coscos\ (\emptyset - \beta))}{(\square\square\square sin(\square)\ \square\square\square sin\ (\emptyset) + coscos\ (\square)\ cos(\emptyset)\ coscos\ (\omega))} \text{ (K, 2011)}$$

2) The reflected radiation factor (R_r):

$$R_r = \frac{\rho\ (1 - cos\beta)}{2}$$

3) The diffuse radiation factor (R_d):

$$R_d = \frac{(1 + cos\beta)}{2}$$

4) Solar radiation on tilt surface (I_T):

$I_T = [(1 - I_d/I_g) * R_b + (I_d/I_g * R_d) + R_r] * I_g$ (K, 2011)

Based on the above numerical calculation, we found maximum solar radiation (=898.45 W/m^2) for tilt surface at 13:30 hrs. IST [1, 16]. The table below shows the solar radiation falling on tilt surface over a different period.

Sr. No.	Time (hrs.)	Solar radiation for tilt solar surface (I_T) (W/m^2)
1	10:00	792.04
2	13:00	892.99
3	16:00	428.64

Table 1 Solar radiation falling on tilt surface of solar panel

Thermal Analysis of Solar (PV) Panel

The objective of this paper is to design and fabrication of a single axis solar (PV) tracker, and use of ANSYS R15 simulation to examine how the photovoltaic panel responds thermally to various environmental conditions. Solar PV panel accurately track the sun's motion to optimize the sunlight it receives. As result it is subjected to changes in temperature and weather conditions that can affect its performance. Therefore, simulation is done in ANSYS workbench R15 software to validate the thermal analysis of solar panel at different period of time.

The following steps are involved in transient thermal simulation of photovoltaic panel.

- **Geometry Creation:** 3D geometry of solar panel is created in ANSYS design modeler.
- **Material Selection:** Thermal properties of each layer of solar panel such as thermal conductivity, density and specific heat capacity are provided as per data given in table 2 (Pavlovic, 2021) [22-25] and also mechanical properties of aluminum are selected from engineering data sources available in ANSYS workbench R15.

Parameter	T (mm)	ρ (Kg/m^3)	K (W/mk)	C_p (J/kg.K)
ETFE	0.28	1730	0.24	1172
EVA	0.2	945	0.35	2090
Silicon Cell	0.4	2330	148	700

PET	0.2	1350	0.27	1275
CFRP	2	1490	6.83	1130
Tape	0.13	1012	0.19	2000

Table 2: Thermal properties of each layer of solar panel

- Mesh Generation: Selected appropriate mesh method, element size and type to generate mesh. Solar panel generated a finite element mesh with 308217 nodes and 44447 elements of the geometry.

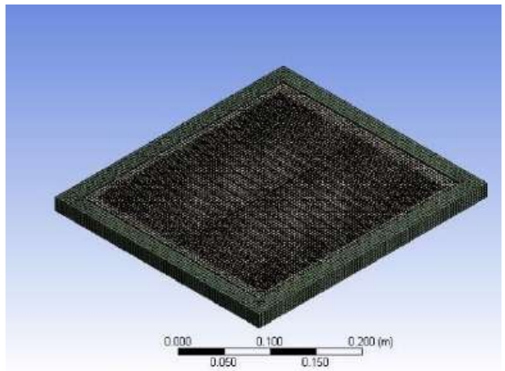

Fig. 3: Meshing of solar panel

- Boundary Conditions: Specified various boundary conditions for transient thermal simulation of solar panel. This includes ambient temperature, Heat flux, Convection and Radiation boundary conditions. Emissivity (Pavlovic, 2021) for ETFE and CFRP is taken as 0.89 [25].

Table 3 shows [25] the absorption, transmission and reflection of solar radiation from solar panel surfaces.

Sr. No.	Material	Absorptivity	Transmissivity	Reflectivity
1	ETFE	0.1	0.83	0.07
2	EVA	0	1	0
3	Silicon Cell	0.97	0	0.03

Table 3: Absorption, transmission, and reflection of solar radiation from PV panel

Boundary conditions applied for transient thermal analysis of solar (PV) panel at maximum temperature are as follows [24-25].

i. The whole solar radiance heat flux falling on tilt surface of solar panel is equal to 898.45 W/m^2.

ii. ETFE layer of solar panel absorbs 10% (=89.845 W/m^2) of total solar radiation and it reflects 7% (=62.89 W/m^2) of solar radiation heat flux falling on solar panel surface (Pavlovic, 2021).

iii. Since EVA is a completely transparent material. Therefore, it doesn't absorb and reflect any solar radiation. But it transmits remaining (=745.72 W/m^2) solar radiation to silicon cells.

iv. But at the monocrystalline silicon cells there is reflectivity toward ETFE which is equal to 3% (=22.38 W/m^2) of solar heat flux incident on it (Pavlovic, 2021). Therefore, the remaining incident heat flux at monocrystalline silicon cells is 723.34 W/m^2. But there is also a generated heat flux from solar panel, maximum generated power by panel is 10 watt and total surface area of PV silicon cells is 0.1269 m^2. Therefore, total heat flux received by monocrystalline silicon cells is 644.54 W/m^2.

v. Convective heat transfer coefficient for solar panel upper surface (h_{up}) is 3.50 W/m^{2}K and for lower surface (h_{lower}) is 1.75 W/m^{2}K.

- Solver: Solver is used to define thermal simulation of solar panel at different boundary conditions.
- Solution: Run the simulation and obtain temperature distribution of silicon cells layer of solar PV panel at different period of time.

RESULTS

Experimental Result

The experimental data for research were gotten from solar panel through sensors and controllers. The output signals of LDRs based on the spectrum of light incident upon their exterior surfaces. ESP 32 microcontroller communicates with LDRs and other sensors and controllers to collect the data in every 2 minutes, and process the result on IoT platform, a possible code was written. As per data received, we found system generates maximum temperature between 1200 hours to 1400 hours and in the morning and evening, the intensity of sunlight falling on solar PV panel is diminishing, and the temperature recorded by controllers are also low as compared to midday. After sunset, solar PV panel returned to its original position. The maximum temperature recorded by the experimental model is 54.1°C at 13:30 hours IST and minimum temperature recorded by system is 30.6°C in the morning at 8:40 hours IST. Similarly, solar panel rotate around 2.5 degrees in every 10 minute or 15° in every hour. Below figures shows the graphical representation of temperature and tilt angle recorded by model over a period.

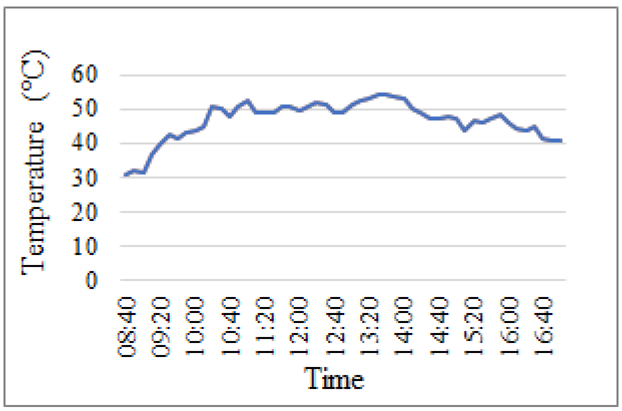

Fig. 4: Graphical representation of temperature Vs time

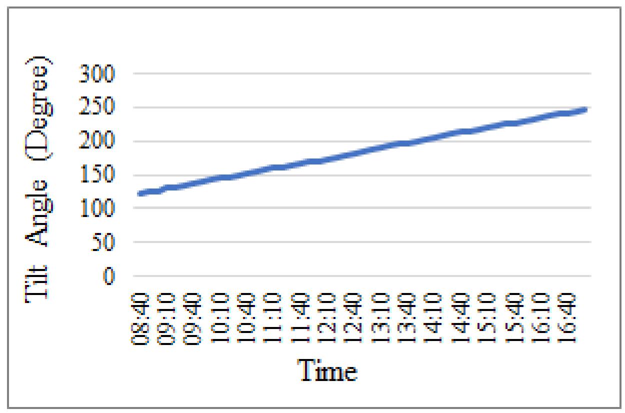

Fig. 5: Graphical representation of tilt angle Vs time

ANSYS SIMULATION RESULT

For the thermal analysis of PV panel, transient thermal simulation [22] was used in ANSYS workbench R15 software to validate the temperature obtained from experimental model at maximum temperature and different period of time recorded by temperature sensor and ESP 32 microcontroller.

The ANSYS simulation results shows almost similar trend to the analytical data received from IoT platform. The Maximum ANSYS temperature was 55.97°C when experimental data was 54.1°C at 13:30 hours IST. Similarly, ANSYS simulation temperature was 44.84°C when experimental model PV cells temperature was 43.9°C at 10:00 hours IST, ANSYS simulation temperature was 54.97°C when experimental model temperature was 51.4°C at 13:00 IST and ANSYS simulation temperature was 48.34°C when experimental model temperature was 46.1°C at 16:00 hours IST respectively.

Thermal behavior of silicon cells at different period are shown in the figure.

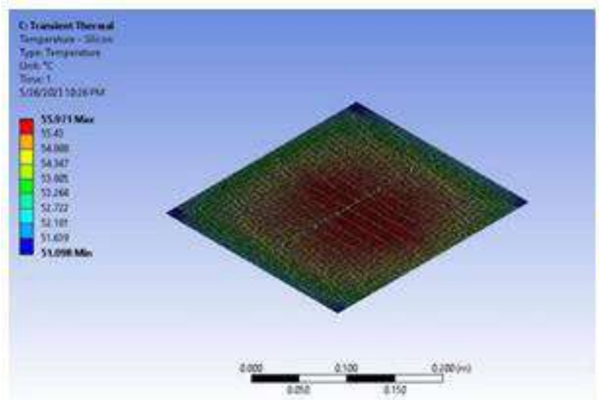

Fig. 6 Thermal simulation of silicon cells at 13:30 IST

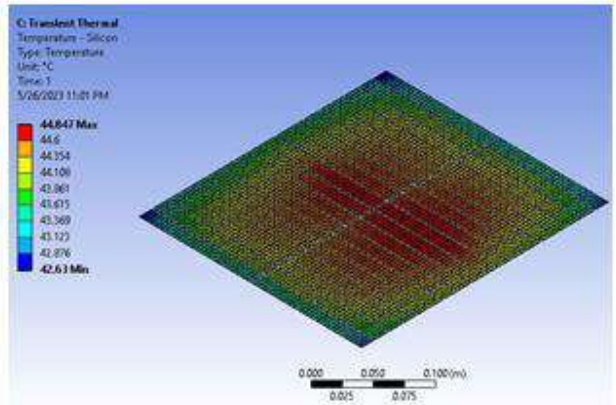

Fig. 7 Thermal simulation of silicon cells at 10:00 IST

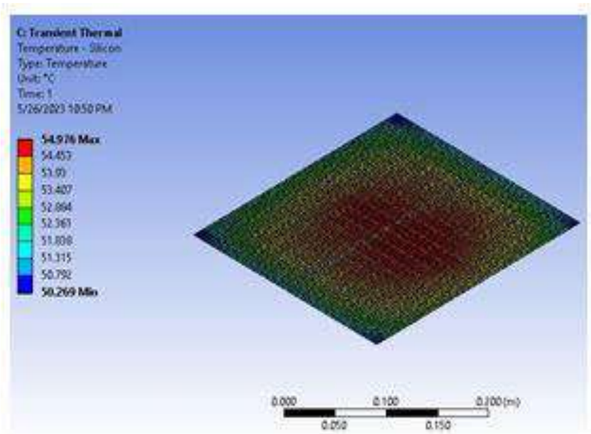

Fig. 8 Thermal simulation of silicon cells at 13:00 IST

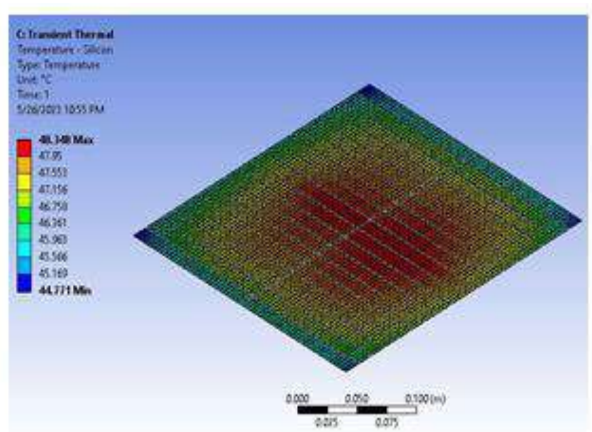

Fig. 9 Thermal simulation of silicon cells at 16:00 IST

Figure below shows the graphical representation of experimental and ANSYS simulation results of temperature profile over a different time period.

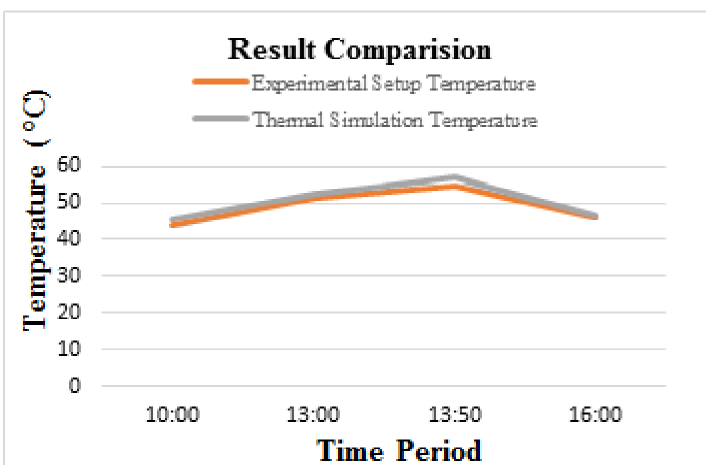

Fig. 10 Comparison of results

As per the comparison of experimental data with ANSYS simulation result, maximum 6.96% increase is seen in the ANSYS Simulation results, which is under acceptable limit.

CONCLUSION

The presented research gives an in-depth knowledge of design, fabrication, and thermal analysis of single axis solar tracker system.

Results getting from an experimental setup and thermal simulation are given below:

- DHT 22 temperature module is used to record the experimental solar panel temperature.
- The maximum temperature recorded by system was in between 1200 hours IST to 1400 hours IST and in the morning and evening, the intensity of sunlight falling on solar panel is diminishing, and the temperature recorded by controller and sensor are also low as compared to midday.
- The ANSYS results shows almost similar trend to the analytical calculation. The maximum temperature of solar panel was recorded by temperature sensor is 54.1°C and ANSYS simulation temperature is 55.97°C at 13:30 hours IST, which is temperature of 1.87°C higher as compared to experimental setup.
- Similarly, ANSYS simulation temperature was 44.84°C when experimental model temperature was 43.9°C at 10:00 hours IST, ANSYS simulation temperature was 54.97°C when experimental PV panel surface temperature was 51.4°C at 13:00 hours IST, and ANSYS simulation temperature was 48.34°C when experimental data was 46.1°C at 16:00 hours IST respectively.
- As per the comparison of experimental data with ANSYS simulation results we found, maximum 6.96% increase is seen in the ANSYS workbench R15 simulation results, which is under acceptable limit.
- The tilt angle of solar panel was optimized by using MPU6050 gyroscope sensor module. Solar panel rotates around 2.5° in every 10 minute or 15° in every hour.
- The system efficiency obtained from experimental setup is around 36.17%.

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