Impact of Temperature & Illumination for Improvement in Photovoltaic System Efficiency

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Abstract—Temperature and Illumination has strong impact on photovoltaic systems output power. This research is focused to boost up the annual power production by investigating combined effect of temperature and Illumination. For this purpose, two solutions are purposed to improve annual power production and efficiency. First purposed solution is solar radiation tracker system to track sun for the optimal amount of radiations depending on the annual weather data available for Pakistan. The tracking system is studied for Horizontal, Vertical and dual axes trackers. It is found that this technique is very useful to boost the power production in most of the months of year over the fixed PV system approach. Second purposed solution is selection of suitable PV module types in which the act of changing the PV module types was investigated. Two types (California Energy Commission module and Sandia module) are used over the conventional simplified silicon crystalline module. The results are very promising, in which a significant improvement is noted in both radiations harvesting and power production over the simplified module. Both these purposed solutions are examined in detail and it shows 20% annual power production improvement for the case of Pakistan.

Keywords: Energy efficiency, photovoltaic systems, radiation monitoring, solar power generation, temperature

1. Introduction

Solar Energy is an important energy resource due to its easy availability, cheapness and cleanness. In these days, solar energy is getting more attention due to its technology that is developing rapidly and it has strong capacity to meet energy demands of modern developing society [1].

A photovoltaic panel is incorporated by assembling many photovoltaic cells which are made of P-N types semiconductor materials. If there is light from sun illuminating on this P-N junction, it converts light energy directly into electrical energy [2].

Overall performance of photovoltaic systems heavily depends on environmental parameters like ambient temperature, solar light intensity and tracking angles [3].

It is observed that with the increase of temperature, solar cell parameters like open circuit voltage, fill factor, output power and efficiency are decreased. This increase in temperature can reduce output power by 0.54%/ °C in case of mono-crystalline module and 0.49% / °C for case of poly-crystalline modules when temperature is increased up to 45°C [4]. For temperature over 25°C, average reduction in efficiency is approximately 0.45% for each degree [5]. This phenomenon becomes more prominent in summer.

To extract maximum output power, it is important that PV system operates at maximum power point (MPP). Location of extreme Power point may vary with temperature and solar radiations. [6-7]. Hence temperature and solar radiations have strong impact on photovoltaic systems output power [8-12].

Solar cells dependence on temperature and its performance has been thoroughly studied by many authors [13-19]. Extensive researches have been proposed to assess the module temperature for effective results and Researchers are focused to identify and develop models that can find and assess the effects of each wavelength of the spectral irradiance on module temperature.

Performance of Photovoltaic system is explained by its efficiency and it is desired to extract maximum power from solar panels.

Ratio of output power generated to the solar radiation input is called efficiency (η) and it can be described as [20]

$$\eta = \frac{Voc * Isc * FF}{Pin} \qquad (1)$$

As we can see from this equation that efficiency of Photovoltaic Systems depends upon open circuit voltage (VOC), short circuit current (ISC) and fill factor (FF). The relation between temperature and these parameters can be shown as follow.

For open circuit voltage, we can write it as [20]

$$\mathrm{Voc} = \frac{KT}{q} ln\left(\frac{\mathrm{Iph}}{Is}\right) + 1 \qquad (2)$$

Where K is Boltzmann Constant, q is electronic charge, T is temperature, Iph is photocurrent while IS represents diode saturation current.

For short circuit current, we can write it as [20]

$$Isc = Is\left(exp\frac{q * Voc}{KT} - 1\right) + Iph \qquad (3)$$

For fill factor (FF), we can write it as [20]

$$FF = \frac{Im * Vm}{Isc * Voc} \qquad (4)$$

Where Vm is maximum voltage and Im is the maximum current.

Equations 2, 3, and 4 show that open circuit voltage, short circuit current and fill factor depends on temperature while efficiency depends on these parameters. All solar cell parameters decrease with increase in temperature except short circuit current which increases [21].

The best model should be designed in such a way that it focuses to boost up the annual power production by investigating these effects.

In this paper, modeling of a single solar PV cell incorporating operating equations and include the dependence of cell temperature and illumination as combined effect is done. Its main objective is to find and maintain operation of PV system at the Maximum Power Point by keeping temperature and solar illuminations in optimal conditions to get maximum output power.

This is done by purposing new tracking solution to harvest and utilize solar radiation as much as possible to increase the system efficiency and boost up the output power. Moreover, a detailed discussion is also done to select suitable type of solar panel to get more power to increase efficiency at same temperature and illumination. Karachi (Pakistan) had been chosen to be the location of our study due to availability of global weather data for whole year easily. These simulations held using Rhino/Grasshopper with 3D environment.

This work opens the gate widely in front of different trends and future study in which the 3D tools and weather data is utilized to study solar electrical system which is the main area of novelty.

2. Proposed Model

In this paper, a 3D simulation environment is run and rendered for a PV system constructed on a specific geometry. These simulations held using Rhinoceros/Grasshopper.

Rhinoceros is a state-of-the-art computer-aided design (CAD) software developed by Robert McNeel & Associates in 1980, which can be used to generate complex geometries and 3D models. Similarly, Grasshopper is a visual programming language developed by David Rutten at Robert McNeel & Associates that runs within the Rhinoceros or simply Rhino 3D Computer Aided design (CAD) application.

Grasshopper provides a visual programming language with a wide range of add-ons, such as Ladybug, Honeybee, Energy Plus, Radiation, and many other useful add-ons that enhance the simulation performance.

Advance uses of Grasshopper include parametric modeling for architecture and fabrication, lighting performance analysis for eco-friendly architecture and Building Energy Consumption.

These simulations held using Rhino/Grasshopper, in which a building/Geometry is designed to have a PV system mounted on its roof to study the solar path, temperature, wind rose and amount of radiation encountered by the building on monthly basis.

The geometry built with a property to be tuned in width and length to meet the desired area of several suggestions. This weather study considers the conditions in Karachi Pakistan based on global actual weather data.

This weather data can be imported to Proposed Model by giving URL of this weather data from verified website that maintains global weather record. Based on above data, the building encounters a known amount of radiation and temperature for each month.

The aim of this work is to enhance the PV system power production considering the collected data. This idea is presented as a solution that improves the act of the PV system to the solar radiation to make it always oriented to the normal direction of the solar radiation. i.e. More radiation harvesting. This approach opens the gate for a very good future work and smart building applications.

Top, Front, Right and Prospective view of Building Design using Rihno/Grasshopper is shown in Fig.1.

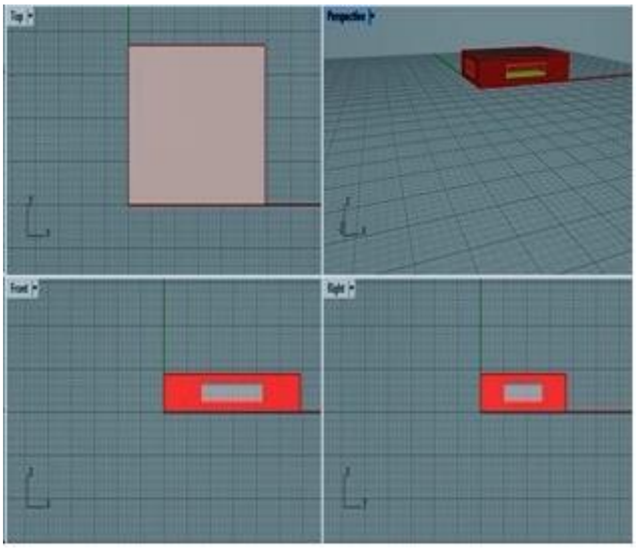

Fig. 1. Top, front, right and prospective view of building design using rihno/grasshopper

The important sections of this purposed model that depicted in Fig. 2, can be explained as follow.

A. The Geometry Section

This section is the one that is responsible for building and previewing the geometry. You can edit the dimensions of the Geometry through the three sliders called: Width, Depth and Height. Using the Width and Depth sliders, you can scale the roof area in which the PV cells will be mounted.

B. Weather Data Section

In this section, based on global weather data, Karachi is to study the weather data that effects on PV system. The. epw component allows you visualize and import different kinds of weather data. In this case, we can visualize the radiation and temperature as the main parameters that affect the PV system.

C. PV Module Selection

Form this section, we can choose three different types of PV modules that affect and enhance the output power while having the same temperature and irradiation. This is one way to enhance the output power by selecting suitable PV Module that gives more output power at same temperature and illumination. Considered PV Modules are Simplified Crystalline PV Module, California Energy Commission (CEC) PV Module and Sandia PV Modules.

D. DC De-rate Factor

To make work and discussion rich, we can use these parameters to study their effect on the system and annual output power to obtain more accurate results.

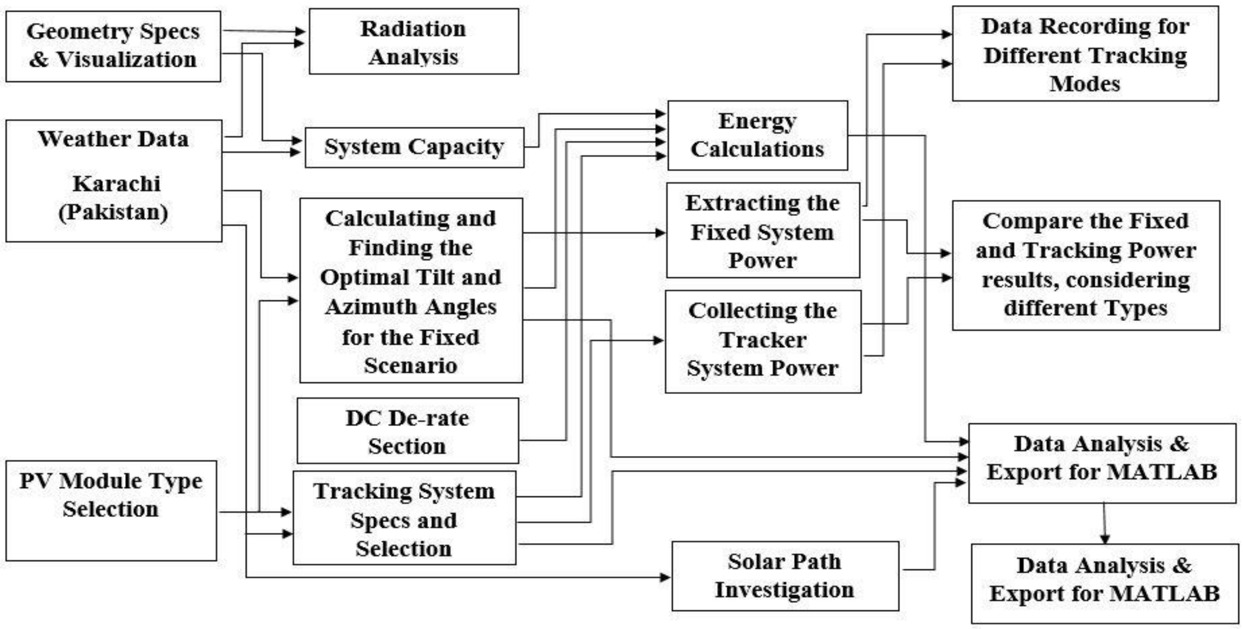

Fig. 2. Layout of purposed model

E. Calculating the Optimal Azimuth and Tilt Angles (Fixed Tracking)

This component calculates the optimal Azimuth and Tilt angles depending on the location data provided from the. epw component for Fixed Tracking System.

F. Calculating the System Capacity

Depending on the area of the roof surface declared, the system size (capacity in KW) of the system is calculated using a small Python code in the python component and then fed to the other component that depends on this value.

In this case, System Capacity is 97.38 KW with scaled area of 540 m2.

G. Tracking System Specs and Properties

This is a very important section, in which you control you tracking system modes in which PV cell can track the sun using: Horizontal Axis, Vertical Axis or Dual Axis. That means that there are two angles to vary: Azimuth and Tilts angles. The precision of the step size can be determined using the two sliders. It should be noted that the higher the slider numbers, the more time needed to process the output data.

H. Energy Calculations

This component calculates the core outputs of the PV system. From this component we can have the power outputs of the fixed and tracking scenarios. Also, we can have the radiation and cell temperature outputs that can be used for post process.

I. Output Power for Different Modes

This block prepares and extracts the output power for tracking and fixed PV systems to the next step for export and visualizes data.

J. Data Analysis For MATLAB

This block gives you the ability to study and analyze different types of data such as Radiation and Temperature. These data can be also exported to MATLAB for different analysis.

K. Solar Path Investigation

Using this component, you can analyze the sun position that throughout the year or even a specified period of the year. This useful when you want to know the exact position of the sun that achieves a kind of data. For example, you can specify the sun positions that achieve amount of radiation more than 800 Wh/m2 in June.

Purposed Model implementation in Rhino/Grasshopper is depicted in Fig. 3.

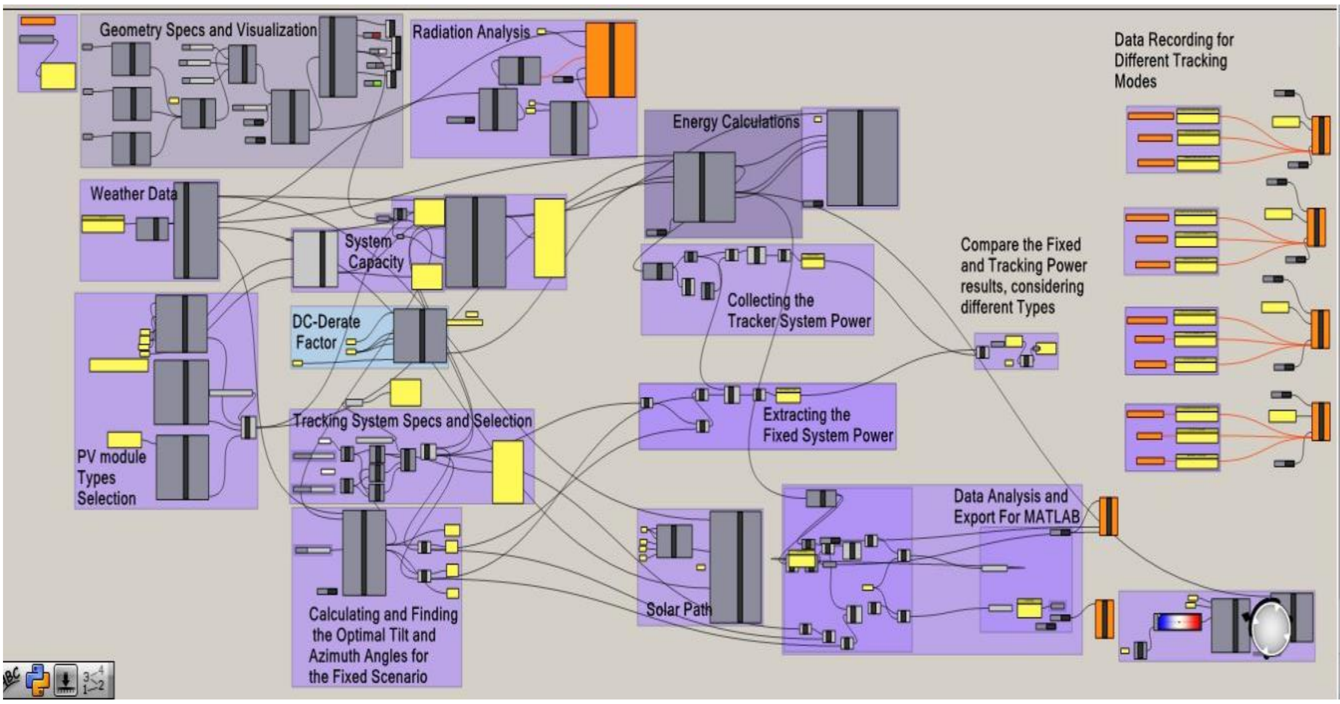

Fig. 3. Purposed model implementation in rhino/grasshopper

3. Working of Proposed Model

The main objective of this paper is to improve the output production of Solar PV System that is affected by Temperature & illumination. First of all, we need verified real time global weather data for the case of Karachi Pakistan.

It is unique property of Rhino/ Grasshopper that by giving weather file URL, all hourly weather data is imported to Model which can be further explained in the Fig. 4 shown below.

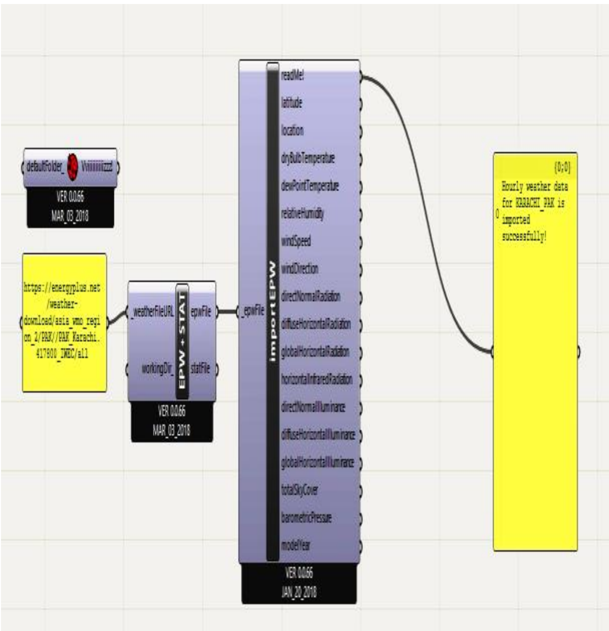

Fig. 4. Import of weather data to proposed model

This hourly weather can be further modified to each day and each month as desired to obtain required results as shown Fig. 5 below.

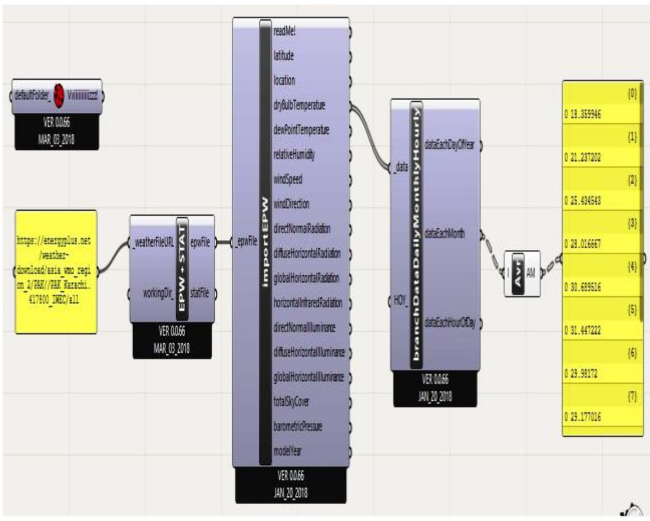

Fig. 5. Import of monthly dry bulb temperature

Monthly Dry bulb Temperature can be seen through a display panel. This export data can be saved in excel form for further process by right clicking on display panel and using command Stream Contents as shown in Fig. 6 below.

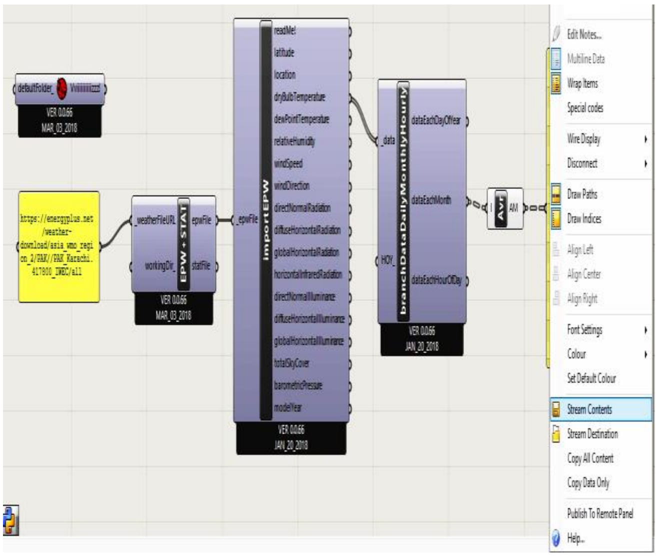

Fig. 6. Import of monthly dry bulb temperature to excel

A. *Import of Weather Data*

As it can be seen that online weather data can be imported for the case of Karachi Pakistan by following above procedure. This imported data has all kind of weather data like Dry Bulb Temperature, Dew Bulb Temperature, Relative Humidity, Global Horizontal Radiation, Global Horizontal Illuminance and Pressure etc. which can be exported to study its effects on PV System as illustrated in Fig. 2. In Table 1, it can be seen that import of average monthly data for the case of Karachi, Pakistan is done using Rhino/Grasshopper.

Table 1. Import of average monthly weather data for the case of Karachi Pakistan using rhino/grasshopper

Month/Mode	Dry Bulb Temperature (C)	Dew Bulb Temperature (C)	Relative Humidity (%)	Wind Speed (m/s)	Global Horizontal Radiation (Wh/m^2)	Global Horizontal Illuminance (lux)	Barometric Pressure (Pa)
Jan	18.359946	4.547177	45.21102	2.761962	776.687	16654.57	101378.4
Feb	21.237202	8.025298	48.33482	2.650298	806.6458	20978.42	101123.4
March	25.434543	12.635215	50.26613	1.478763	915.1156	24613.71	100877.3
April	28.016667	19.008056	61.47917	2.764028	932.2721	27940.28	100493.5
May	30.689516	22.613575	65.2621	3.724194	1076.96	32158.33	100189.1
June	31.447222	24.883889	69.55556	4.886806	867.9521	27233.89	99810.83
July	29.98172	24.045161	71.08737	5.283737	735.4215	22442.74	99632.26
August	29.177016	24.352823	75.78763	4.970161	690.0149	20915.99	99906.18
Sep.	28.639028	22.815139	71.76806	4.131111	773.7719	23009.86	100172.9
Oct.	28.23414	14.242473	48.98387	3.205242	1012.578	24625.54	100796.6
Nov.	23.654306	11.418194	52.49028	2.354167	882.8442	19597.36	101098.3
Dec.	19.649866	9.374866	55.40054	1.044892	776.1544	16069.89	101263.2

B. *Building Environment Radiation and Temperature*

The Ladybug add-on was utilized to study and calculate the solar irradiance on the modules and also temperature that affect the building per hour for the whole year. Ladybug contains different components that process weather data.

In Fig. 7, it can be clearly seen that most of year has high temperature in Karachi, which affect the solar panel performance. On the other hand, this is benefit when studying the amount of radiation available for the solar system mounted above the building. Solar Path and Sun Positions for Degrees between 0 & 32 °C using Rhino/Grasshopper can be visualize as figure shown below.

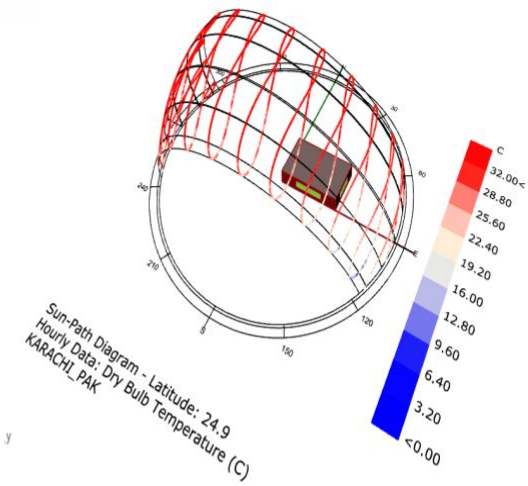

Fig. 7. Solar path and sun positions for degrees between 0 & 32 °C

If we want to have the only values of temperature greater than 25 °C and radiation higher than 600Wh/m2, we can have the following Fig. 8.

As we know that effective period is longer in summer where the day time becomes longer as shown in Fig. 8, which is as expected. The total output values of temperature and radiation is averaged over monthly basis and then exported to an Excel file for post-process as discussed earlier. Solar Path and Sun Positions for Radiation between 0 & 1000Wh/m2using Rhino/Grasshopper can be visualize as Fig. 8 shown below.

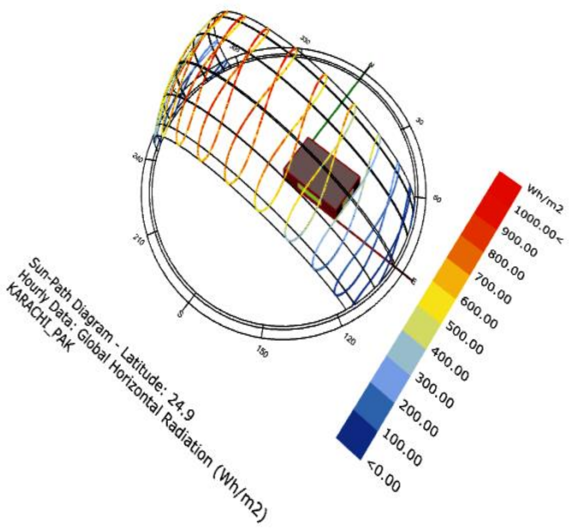

Fig. 8. Solar path and sun Positions for radiation between 0 &1000Wh/m^2

Solar Path and Sun Positions for Radiation higher than 600Wh/m^2 and Temperature greater than 25 °C is illustrated in Fig. 9.

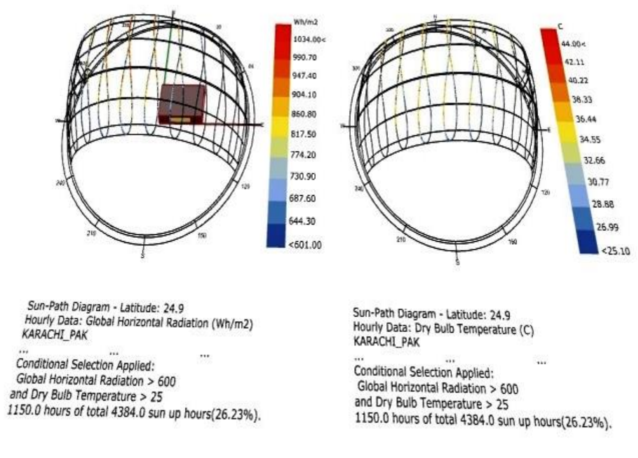

Fig. 9. Solar path and sun positions for radiation higher than 600Wh/m^2 and temperature greater than 25 °C

4. Results and Discussion

In the Grasshopper file, all the parameters can be set and the simulations can be started. The Grasshopper simulation depends on two aspects in order to enhance the PV output power considering the same available radiation and the same temperature.

First aspect is using a three-mode solar tracking system in which a fixed PV system is compared to a three-mode movable PV one with Vertical axis, Horizontal axis or Dual Axis modes.

Second aspect is changing the type of the PV module in which three PV module types are considered: Basic Crystalline-Silicon (c-Si) module, California Energy Commission (CEC) module and Sandia module.

While the building energy and the radiation simulations are conducted within Grasshopper, the PV calculations take place within Python. After the system is run for every simulation approach, the radiation and temperature results can be exported to excel files.

C. Output Power Results

The simulation had run for every PV module type. Each time, the PV mode, axis property is changed to a different axis mode. The fixed PV module simulation had been run for optimal inclination and azimuth angles which were found to be 27 and 180 degrees respectively. On the other hand, each of the vertical and horizontal tracker modes had run to track eleven angle possibilities. Finally, the dual axes mode had been run for 11x11 angle combinations, i.e. total of 121 combination possibilities. The number of possibilities and be increased up to 90 for vertical tracker and to 180 for horizontal one but a very powerful processor will be needed because this will take very large amount of time to finish, up to days for normal laptop processor.

1) Output Power Improvement Using a Three-Mode Solar Tracking System:

In Fig. 10, the mode has changed over to fixed panels, Vertical axis tracker, Horizontal axis tracker and finally dual axis tracker. The PV module had been chosen to be of Sandia type characteristics. As can be seen from the Fig. 10, the dual axes mode achieved the best performance over all the other types. On the other hand, it can be noticed that the vertical tracker, inclination auto-adaptation, achieved performance very near to the dual one in July, August and Sep. This means that in terms of cost, the system can be set to only vertically track in these months. Finally, the horizontal tracker and the fixed type exhibited the poorest performance.

Table 2. Power production for sandia PV module monthly PV

Month/Mode	Fixed (KW)	Vertical (KW)	Horizontal (KW)	Dual-Axes (KW)
Jan	12601.55	13447.1	13198.78	14680.62
Feb	13028.09	14197.3	13281.1	15191.25
March	14565.38	16241.4	14604.18	16905.54
April	14538.45	17002.2	14946.14	17688.84
May	15593.25	19370.3	16928.55	20234.08
June	12673.94	15346.7	14006.95	15870.29
July	11335.37	13002.7	12268.45	13308.65
August	11070.42	12304.9	11570.58	12565.96
Sep.	12632.09	14049.9	12767.5	14453
Oct.	15921.29	17791.1	16117.29	19162.18
Nov.	13631.53	14728.4	14226.7	16134.89
Dec.	12158.89	12889.6	12868.16	14164.41

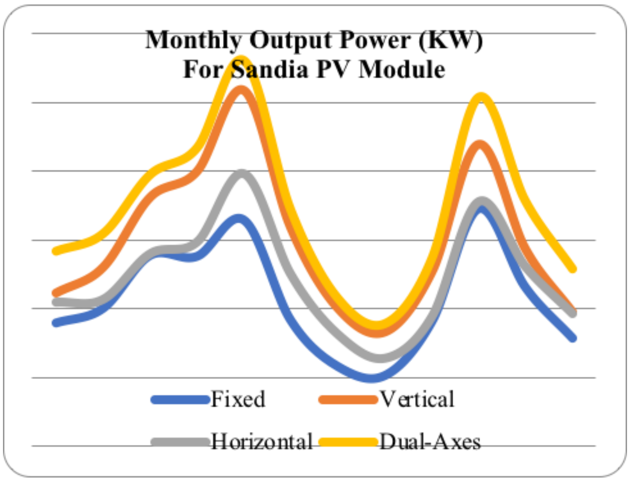

Fig. 10. Monthly PV power production for sandia PV module

Similarly, the simulation had been run simplified and CEC PV modules. The dual axes maintain the best performance, as shown in Figs. 11 and 12. However, in the simplified module, the vertical and dual axes exhibit almost same performance. Which means that, in terms of operation cost, the vertical tracker is better choice if simplified PV module is to be chosen.

Table 3. Monthly PV power production for simplified PV module

Month/ Mode	Fixed (KW)	Vertical (KW)	Horizontal (KW)	Dual-Axes (KW)
Jan	12231.75	13052.97	12839.72	13052.97
Feb	12741.1	13925.18	13006.18	13925.18
March	14351.99	16077.7	14393.18	16077.7
April	14362.84	16818.18	14770.36	16818.18
May	15341.72	19106.18	16676.59	19106.18
June	12349.25	14959.02	13659.68	14959.02
July	10967.06	12582.99	11884.02	12582.99
August	10707.57	11928.72	11207.15	11928.72
Sep.	12253.08	13691.72	12391.68	13691.72
Oct.	15618.96	17486.28	15823.26	17486.28
Nov.	13304.43	14397.45	13922.26	14397.45
Dec.	11868.6	12586.83	12605.14	12586.83

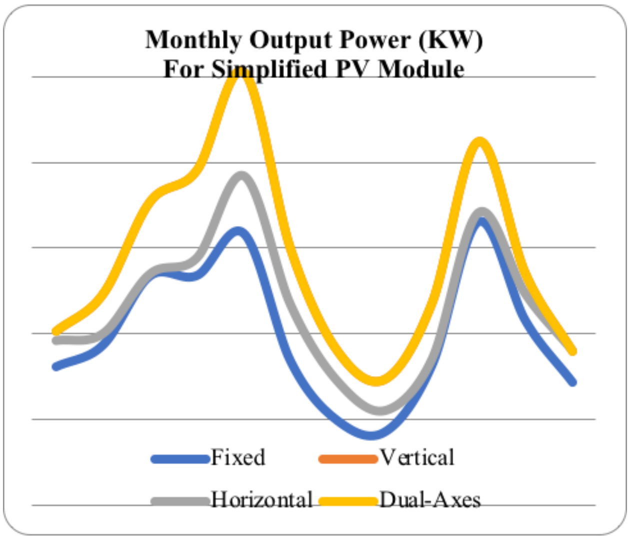

Fig. 11. Monthly power production for simplified PV module

Moreover, in the simplified PV module, the performance of optimal angles fixed system show nearly the same as dual in January and December. This is because of the short-day hours in winter, and because also of low temperature means that the system can be switched to static optimal angles and actuation power can be reserved in this months, if simplified PV modules is mounted.

Table 4. Monthly PV power production for simplified CEC module

Month/ Mode	Fixed (KW)	Vertical (KW)	Horizontal (KW)	Dual-Axes (KW)
Jan	12129.73	13004.35	12774.222	14285.47
Feb	12592.96	13815.56	12870.122	14846.63
March	14032.76	15784.7	14063.629	16464.72
April	14032.41	16629.79	14436.399	17331.64
May	15097.19	19168.21	16517.682	20080.57
June	12081.37	14889.1	13416.375	15426.70
July	10654	12350.72	11515.335	12644.44
August	10440.13	11700.32	10883.612	11951.84
Sep.	12132.38	13612.11	12247.383	14029.70
Oct.	15623.66	17621.55	15842.855	19062.52
Nov.	13211.04	14361.56	13858.238	15831.16
Dec.	11557.93	12296.5	12300.416	13583.49

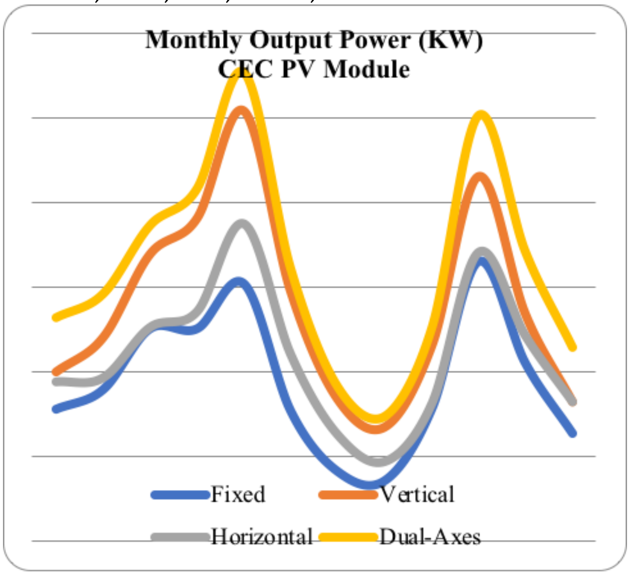

Fig. 12. Monthly power production for CEC PV module

2) Output Power Improvement by Changing the Type of the PV Module:

Output power can also be increased by using suitable type of PV Module which can give more power at same temperature and illumination.

A comparison between the PV modules types is held as shown in Fig. 13, considering the Dual axes mode as a reference mode. The Sandia and CEC showed almost the same performance in terms of power production. Additionally, they perform better than the simplified module, especially, in winter and autumn, in which the performance gap becomes larger.

Table 5. Monthly PV power production for different PV modules considering dual axis mode

Month/ Mode	Simplified (KW)	Sandia (KW)	CEC (KW)
Jan	13052.973	14680.62	14285.48
Feb	13925.177	15191.25	14846.64
March	16077.696	16905.54	16464.73
April	16818.18	17688.84	17331.65
May	19106.18	20234.08	20080.57
June	14959.025	15870.29	15426.7
July	12582.993	13308.65	12644.44
August	11928.715	12565.96	11951.84
Sep.	13691.722	14453	14029.71
Oct.	17486.275	19162.18	19062.52
Nov.	14397.445	16134.89	15831.17
Dec.	12586.827	14164.41	13583.5

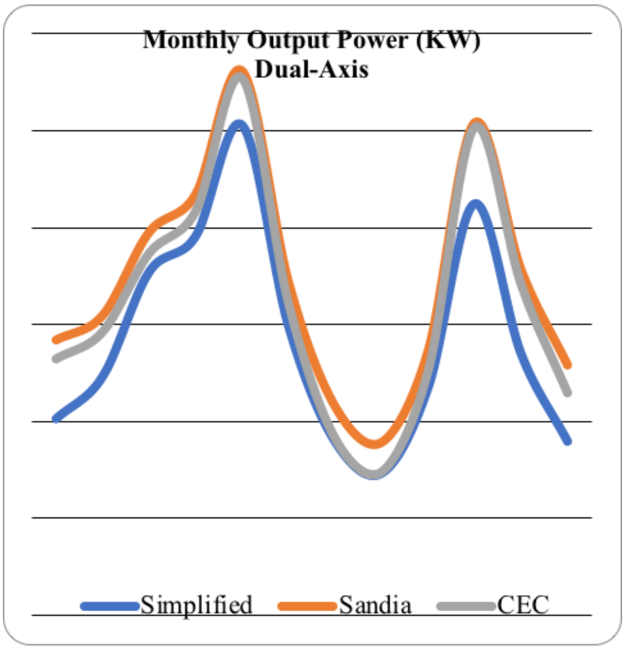

Fig. 13. Monthly power production for different PV modules considering dual axis mode

Good to mention that although all of the three PV modules used in this modulation encounter the same amount of radiation, their performance in terms of power production differs. It can be clearly depicted when compared on annual power production basis, as shown in Fig. 14. Sandia with dual axed mode produces the largest amount of annual power. The CEC and dual was the second-best choice. While the simplified fixed one was the worst, with amount less of about 20% of production.

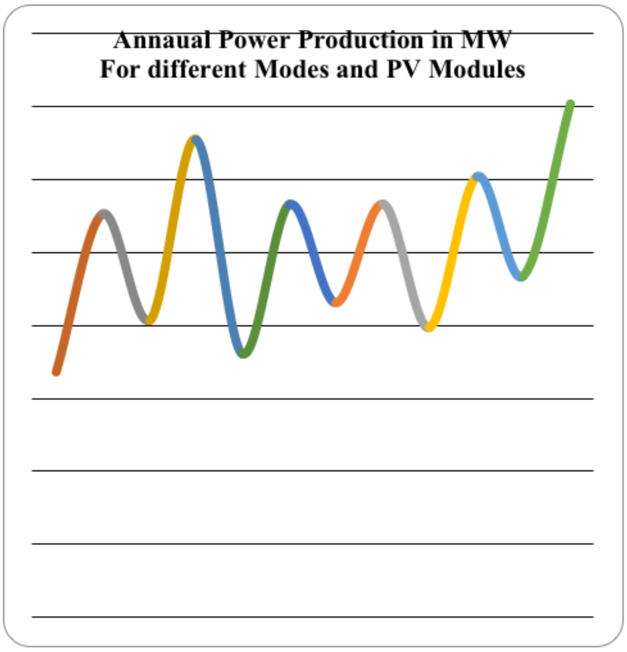

Fig. 14. Annual power production for different tracking modes and PV modules

D. Radiation and Temperature Analysis

Similarly, Radiation and Temperature Analysis can be done for Fixed, Vertical, Horizontal and Dual Axes to increase the system efficiency and boost up the output power.

Table 6. Monthly radiation harvesting for different system modes in WH/M^2

Month/Mode	Fixed	Vertical	Horizontal	Dual-Axes
Jan	736.8774	786.351	776.687	865.5974
Feb	788.6871	860.2402	806.6458	925.7285
March	912.8418	1022.248	915.1156	1066.06
April	905.8432	1065.621	932.2721	1109.682
May	986.1434	1239.032	1076.96	1297.781
June	781.4405	951.4231	867.9521	985.895
July	679.4337	777.0927	735.4215	795.9442
August	660.9687	732.4708	690.0149	748.4374
Sep.	765.8844	850.9746	773.7719	876.0288
Oct.	998.5374	1118.989	1012.578	1211.288
Nov.	840.3036	908.8173	882.8442	1005.463
Dec.	726.0674	770.3797	776.1544	857.4294

Fig. 15, summarizes the previous explained idea. It compared the fixed and tracking modes behavior to the same amount of radiation of the building surface.

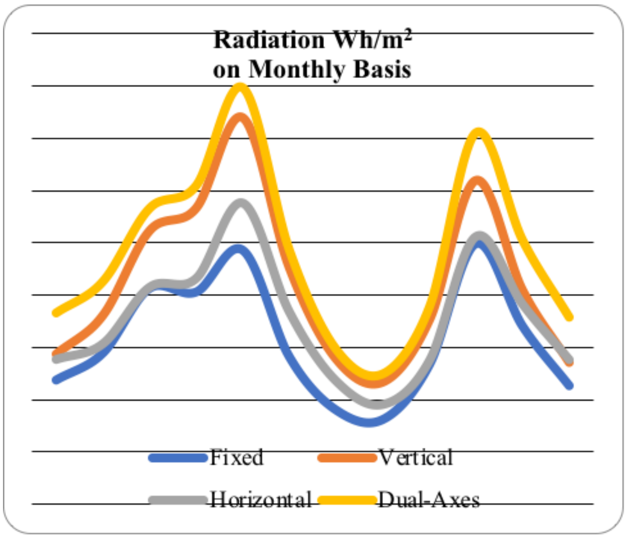

Fig. 15. Monthly radiation harvesting for different system modes in Wh/m^2

As expected, the dual axes PV system harvests the largest amount of radiation. So, it produces the largest annual amount of power as seen in above figure. The vertical tracker achieves the second annual rank of radiation and power production. However, it can be noticed that during summer, the dual and vertical trackers harvest almost the same amount of radiation. Horizontal tracker and fixed PV showed the least amounts of radiation harvesting and power production. Further in Fig. 16, comparing the same mode of operation for different type, Temperature behavior of Sandia Module at different modes can be shown as follow.

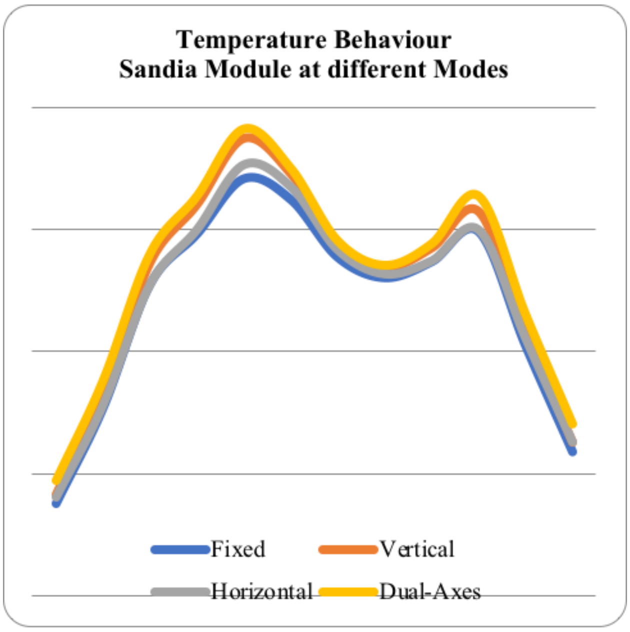

Fig. 16. Temperature behavior of sandia module at different modes

We can see for example for vertical mode, the Sandia converts the same amount of radiation for larger amount of power than simplified and CEC modules. This gives a significant indication for the importance of PV type selection before construction.

Similarly, Fig.17 represents effect of temperature on different PV system. There were slight differences in the temperature of the PV surfaces. Compared to the previous results, it can be concluded that despite of the slight temperature rising in Sandia type and dual axes modules, their power production was the highest amongst the other options.

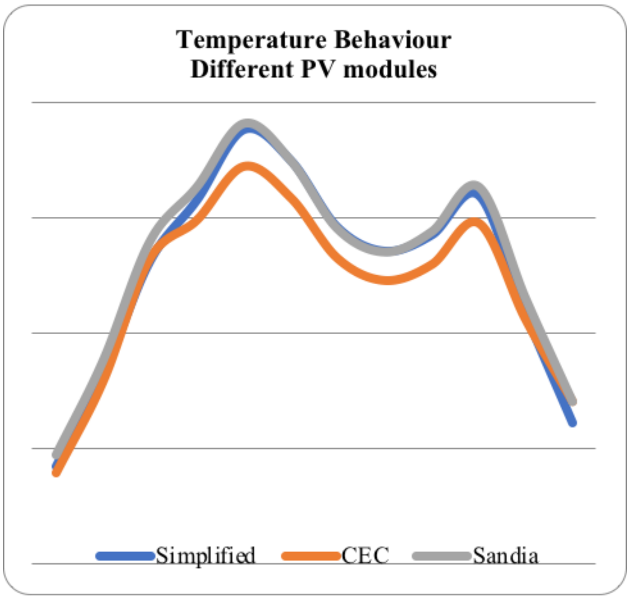

Fig. 17. PV module type's temperature behavior

5. Cost of Tracking System

Tracking system has two types. One is active tracking system which is motorized while other is called passive tracking system without motor. Tracking systems are made of mechanical parts like actuator integrated with AC or DC motor, gear, Electronic parts like motor drive and controller, power supply and sun sensor. Its cost can be considered as a percent of the construction price which will be one time. Most important case is about the power consumption by the tracker which can be reduced to its minimum cost by using pneumatic actuators that store energy as pressured air in the times of over production and uses it when tracking is required.

6. Conclusion

In this paper, the problem of enhancing a Solar PV System, considering the same environment condition was investigated. The main aim was to boost up the annual power production while having the same amount of solar radiation and also the same temperature conditions. In order to maintain such environment, the Rhinoceros power 3D program with its valuable Grasshopper plug-in was employed. Two approaches were proposed to maximize the solar radiation harvesting process :(1) Solar Radiation Tracker System where the PV system is equipped with actuators that enable the panels to track the sun for the optimal amount of radiation, depending on the annual weather data available for Pakistan. The tracking was studied for three cases, Horizontal, Vertical and Dual axes trackers. It was found that this technique was very useful to boost the power production in most of the months of the year, over the fixed PV system approach, (2) PV Module Types where the act of changing the PV module type was investigated. Two types were used over the conventional Silicon-Crystalline, simplified module: CEC and Sandia modules. The results were very promising, in which a significant enhancement was noted in both radiation harvesting and power production over the simplified module. This work opens the gate widely in front of different trends and future study in which the 3D tools and weather data were utilized to study solar electrical system which is the main area of novelty. Future studies are studying the effect of shadowing, depending on its annual data and solar sun path, on the solar systems production and choose the optimal locations and suggestions to minimize the effect of shadowing. Moreover, further studies on the effect of wind and wind speed on PV system construction and production can be held. Last but not least, the Architecture design and specs can be studied to apply adaptive solar panels as building facades, which yield to power production and also to building shading. Based on intensive work, this can lead to reduce the power consumption of heating and cooling systems while having a clean source of energy that contribute to the free power sources.

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Reference

[1] Awan, M.M.A. and Mahmood, T., “Optimization of maximum power point tracking flower pollination algorithm for a standalone solar photovoltaic system”, Mehran University Research Journal of Engineering and Technology, 39(2), pp.267-278, 2020.

[2] Afzal Awan, M.M. and Mahmood, T., “A novel ten check maximum power point tracking algorithm for a standalone solar photovoltaic system”, Electronics, 7(11), p.327, 2018.

[3] Awan, M.M.A. and Awan, F.G., “Improvement of maximum power point tracking perturb and observe algorithm for a standalone solar photovoltaic system”, Mehran University Research Journal of Engineering & Technology, 36(3), pp.501-510, 2017.

[4] Q. M. Aish, "Temperature Effect on Photovoltaic Modules Power Drop," Al-Khwarizmi Engineering Journal,, vol. 11, no. 2, pp. 62- 73, 2015.

[5] C. G. Popovici, S. V. Hudișteanu, T. D. Mateescu and N.-C. Chereches, "Efficiency improvement of photovoltaic panels by using air cooled heat sinks," Energy Procedia, Elsevier, vol. 85, no. 1, p. 425 – 432, 2016

[6] A.G. Ali, M. S. Seyed, S. Asma. “A high performance MPP-Maximum Power Point tracker for PV systems.” International Journal of Electrical Power & Energy Systems, vol. 53, pp. 237–243, 2013.

[7] A. N.Allah, M. Saied, M. Mustafa and T. Abdel-Moneim. “A Survey of Maximum PPT techniques of PV Systems,” Browse Conference Publications, Energytech, IEEE, pp. 1-17,2012.

[8] R.Pon Vengatesh and S. Edward Rajan, "Investigation of the effects of homogeneous and heterogeneous solar irradiations on multicrystal PV module under various configurations," IET Renewable Power Generation, vol. 9, no. 3, p. 245–254, 2015.

[9] F. Reis, C. Guerreiro, F. Batista, T. Pimentel, M. Pravettoni, J. Wemans, G. Sorasio and C. M. Brito, "Modeling the Effects of Inhomogeneous Irradiation and Temperature Profile on CPV Solar Cell Behaviour," IEEE Journal of Photovoltaics, vol. 5, no. 1, pp. 112 - 122, 2015.

[10] B. Dubey, D. Tiwari and D. R. Kumar, "Effect of temperature variations over photovoltaic modules efficiency of different technologies at NOCT," in IEEE Students' Conference on Electrical, Electronics and Computer Science, 2016.

[11] Y.K. Sanusi, G.R. Fajinmi, and E.B Babatunde, “Effects ofambient temperature on the performance of a photovoltaic solarsystem in a tropical area,” vol. 12, The Pacific Journal ofScience and Technology 12.2, pp. 176-180, 2011.

[12] P. Arjyadharal, Ali S.M, and J. Chitralekha, “Analysis of solar PV cell performance with changing irradiance and temperature,” International Journal of Engineering and Computer Science, vol. 1, pp. 214-220, 2013.

[13] D.M. Tobnaghi and D. Naderi, "The Effect of Solar Radiation and Temperature on Solar cells Performance," Extensive Journal of Applied Sciences, vol. 3, no. 2, pp. 39-43, 2015.

[14] P. Singh and N. M. Ravindra, "Temperature dependence of solar cell performance-an analysis," Solar Energy Materials and Solar Cells, vol. 101, pp. 36-45, 2012.
[15] J. Ahmad, F. Spertino, A. Ciocia and P. Di Leo, "A Maximum Power Point Tracker for Module Integrated PV Systems under Rapidly Changing Irradiance Conditions," in International Conference on Smart Grid and Clean Energy Technologies, 2015.
[16] K. A. Moharram,M.S.Abd-Elhady,H.A.Kandil,H.El-sherif, "Enhancing the performance of photovoltic panels by water cooling," Ain Shams Engineering Journal,vol.4,pp.869-877, 2013.
[17] A. Pradhan, B. Panda, "Performance analysis of photovoltaic module at changing Environmental condition using Matlab Simulink," International Journal of Applied Engineering Research, vol.12, no.13, pp.3677-3683, 2017.
[18] A.M.Muzathik, "Photovoltic Modules Operating Temperature Estimation Using a Simple Corelation,"International Journal of Energy Engineering, vol.4, issue 4.,pp.151-158, August 2014.
[19] S.A.Abdulgafar,O.S.Omar,K.M.Yousif, " Improving The Efficiency of Polycrystalline Solar Panel via Water Immersion Method,"International Journal of Innovative Research in Science,Engineering & Technology, vol.3, issue 1.,pp.8127-8132, January 2014.
[20] Q. A. H. Al-Naser, N. M. A. Al-barghoothi and N. A. S. Al-Ali, "The Effect of Temperature Variations on Solar Cell Efficiency," International Journal of Engineering, Business and Enterprise Applications, vol. 4, no. 2, pp. 108-112, 2013.
[21] AN. H. Zaini, M. Z. Ab Kadir, M. Izadi, N. I. Ahmad, M. A. M Radzi and N. Azis, "The Effect of Temperature on a Mono-crystalline Solar PV Panel," in IEEE Conference on Energy Conversion (CENCON), pp. 249-253, 2015.