SHODH SANGAM -- A RKDF University Journal of Science and Engineering

Evaluation of convective thermal effects in photovoltaic modules and arrays

Syed Saif Jibran[1], Dr. Sohail Bux[2]
[1]MTech Scholar, [2]Professor
[1]Department of Mechanical Engineering, Agnos College of Technology, Bhopal, India
[2]Department of Mechanical Engineering, Agnos College of Technology, Bhopal, India
syedsaifjibran@gmail.com[1] buxsohail@gmail.com[2]

Abstract — ***Photovoltaic module and cluster execution has been seen to be influenced by twists because of diminished warm misfortune. As the utilization of sunlight based modules expands, comprehend these warm impacts and record for them during plan and arranging. This research gives an outline to this proposal by clarifying the motivation behind this work, which is to investigate and measure the effect by various components, for example, wind speed, wind heading, sun powered irradiance, situating, and direction. Additionally, this postulation is coordinated into three diverse contextual investigations, utilizing various strategies for examination to notice the warm effect of wind on module execution. Spotlights on a solitary module that is fixed onto a top of a structure and concentrates how the ideal slant point situating is affected by various breeze rates and wind bearings by utilizing scientific strategies. Wind speed and wind course assumed an extremely negligible part in changing the ideal slant point choice, yet it was shown that the increment in warm convection prompted more prominent effectiveness. on a PV cluster on the top of a structure to perceive what changing air conditions meant for the general hotness move of the exhibit. This information was utilized to evaluate an observational model to address this wonder. It was tracked down that the hotness move over the PV cluster was extraordinarily impacted by wind speed, and that high surrounding temperatures at higher breeze speeds contrarily influenced the exhibition because of the expansion in the warming burden on the exhibit. Another perception was that radiation heat move was more predominant at lower wind speeds, while convective hotness move ruled at higher breeze speeds.***

Keywords — ***Photo-Voltic,Wind,Convective, Array, Solar Model***

I. Introduction

Sun powered energy is one of the main environmentally friendly power sources in California because of its wealth and diminishing expense [1, 2]. In particular, photovoltaic (PV) energy frameworks have been broadly introduced in the previous many years [3, 4]. Some PV modules are touchy to warm, and their presentation will in general diminish at high working temperatures [5, 6], which are reliant upon sun based irradiance, the situating of the module, and the natural conditions [7, 8]. These ecological conditions are reliant upon the PV module's encompassing constructions and wind stream. The impact of sunlight based irradiance has been widely examined, and various work have zeroed in on the best way to ideally situate PV modules to boost energy creation [9]. Then again other works have concentrated on the impacts of wind on PV modules. [15]. Be that as it may, how convective impacts ought to be considered in plan choices stays hazy, like their impact on the ideal direction of sunlight based modules. Along these lines, the fundamental focal point of the Section 2 is to concentrate on what warm convection means for the direction once sun based and wind impacts are both thought of. It is grounded that the effectiveness of a PV exhibit is reliant upon temperature, which is influenced by elements, for example, surrounding temperature and wind speed [22, 23]. As of late, there has been critical interest in concentrating because of the previously mentioned factors on PV temperature. In spite of the fact that it is notable that higher temperatures adversely influence PV execution, there is no agreement on the quantitative outcomes [22]. The warm impacts on the sun powered exhibit will be researched dependent on yearly gathered information, which will be contrasted with computational liquid elements (CFD) reenactments and an experimental model from PVsyst. The exploratory information will be utilized to see how the cluster heat move coefficient changes dependent on changing barometrical conditions. The dividing between sun based modules has been concentrated by and large and its impacts on the primary elements on the modules. Nonetheless, there are less investigations that analyze how warm impacts change dependent on the optimal design between the modules [20]. The focal point of Section 4, is to research what couple warmed modules mean for the warm convection of the modules. This part used air stream tests utilizing two hotness modules pair, while having shifted wind velocities and dividing, to see how warm convection changes dependent on these vari-ables. Part 5 sums up the three sections of this proposition and outline the principle ends drawn from results and how these discoveries add to understanding convective hotness move on PV modules and exhibits.

Solar Model

This section describes the solar model used to determine the total solar flux striking the PV module. The total solar flux is a function of the module’s orientations, namely the tilt angle and azimuth angle. Figure 2.1 presents a visualisation of solar model.

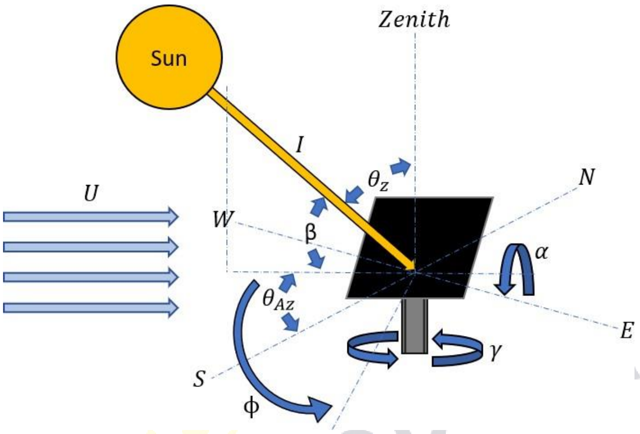

Figure:Visualization of solar model.

This figure illustrates a solar PV module receiving solar radiation from the sun with wind blowing across the module. In this scenario, the total solar flux, I, is the total radiation received, which is a function of the zenith angle, θz, the azimuth angle, θAz, and the tilt angle, α. Wind is blowing on the module at a speed of U , with γ being the direction of the incoming wind relative to the module position, or yaw angle.

Thermal Model

This subsection presents the thermal model used in this chapter to quantify the convective effects on the PV module. After performing an energy balance on the module, it can be shown that a PV module experiences radiation from the sun, convection from the wind, exchanges thermal radiation with its surrounding, and produces electrical power. Equation 2.10 shows how the power from the sun (Qsun) is absorbed by a module.

Natural Convection

Nusselt number is determined in two ways, depending on the type of convection the PV surfaces are undergoing. In this work, it is assumed that the top surface of the PV module experiences forced convection and the bottom surface of the module experiences natural convection due to the module's proximity to ground impeding forced flow.

Forced Convection

This subsection presents the warm model utilized for the constrained convection on the top surface. The conditions are gotten from the outcomes introduced by Wu et al. [21]. They directed tests for a scope of various stream speeds (0.5 m/s, 1.5 m/s, 3.0 m/s, 7.0 m/s, 9.0 m/s), yaw points (0◦ to 75◦ at augmentations of 15◦), and slant points (10◦ to 80◦). Their outcomes were then digitized and afterward detailed into numerical articulations that address the practices saw in their tests, which are recorded in the Supplement. Conditions for Nusselt number were exactly found and fitted, representing differing wind speed, yaw point, and slant point. These equations are utilized for deciding the Nusselt number at the top surface (Nutop) of the PV module. The following segment depicts the mathematical strategy just as the test subtleties utilized in this work.

Numerical Methodology

This section applies the mathematical model shown in previous sections to predict the performance of the PV modules under different orientations. The mathematical model is a function of the wind speed, tilt and yaw angles. This model utilizes the National Solar Radiation Database (NSRDB) data from 2018 [17] to obtain solar radiation data based on the location of the PV module. It should be noted that the 2018 NSRDB data does not include the solar azimuth data, thus the azimuth angle has been extracted from the 2010 data [17] to use in this work. The solar zenith values of the two years are consistent and similar, thus the 2010 solar azimuth angle seems to be appropriate to be used in combination with 2018 data[17].

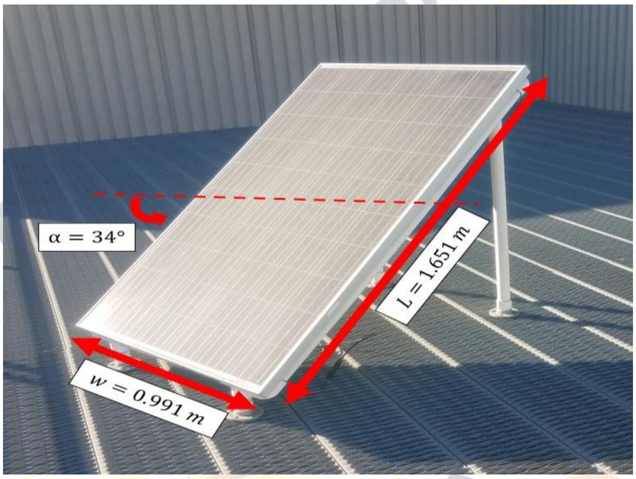

Figure:Solar module installed on the roof

II. LITERATURE REVIEW

The respond to the previously mentioned question, convective impacts on PV modules should be surely known. Existing work in the writing including convective cooling of PV modules essentially centered around exhibiting that convective impacts can further develop PV energy creation because of temperature reliance of PV transformation effectiveness [17, 18, 16, 15, 30]. These work can extensively fall into two methodologies: 1) test and 2) mathematical reproductions. The trial approach regularly include air stream or in situ experimenta-tion. Abiola-Ogedengbe et al.[24] led examinations to analyze the breeze consequences for a solitary PV module, and found that breeze stream over the modules can further develop PV transformation productivity. They discovered a connection between PV proficiency and slant point comparative with an even and consistent breeze [24]. Wu et al. [11] led an exploratory investigation of regular convection heat move from a non-consistently warmed level plate reproducing a PV module. They portrayed the outcomes as an element of Nusselt number. Different scientists have additionally led analyses to measure the outcomes, by portraying convective impacts dependent on wind stream [22, 22]. Mathematical reproductions have been performed to concentrate on convective cooling on sun based modules. Jubayer et al. [23] used computational liquid elements (CFD) to concentrate on warm impacts of altering the approaching breeze bearing. Tahani et al. [23] performed CFD recreations to examine what twist means for the ideal slant point of PV modules. Wu et al. [21] led a broad warm concentrate on PV still up in the air the connections between the breeze course, slant point, and wind speed to convective hotness move. Their arrangement comprised of PV module with all surface thermally protected aside from the top surface. This module was then shifted and yawed to notice the impacts at various breeze velocities and this was accomplished for quite some time and yaw points. This information was then used to decide Nusselt numbers. They presumed that slant point, yaw point, and wind speed essentially influence the cooling load on the module. The discoveries from Wu et al. is utilized widely in this work. Their information is utilized to define numerical models to relate wind speed, yaw and slant points to Nusselt numbers. This segment of the intends to decide what convective impacts will mean for the ideal direction of a PV module. This part investigates a clever technique for how to foresee the effect on PV execution, when convective impacts are thought of, while picking a slant plot for the PV module. This work works off past work by incorporating the current warm outcomes to a sun oriented model. Then, at that point, two contextual analyses are performed.

III. RESEARCH METHODOLOGY

This section applies the mathematical model shown in previous sections to predict the performance of the PV modules under different orientations. The mathematical model is a function of the wind speed, tilt and yaw angles. This model utilizes the National Solar Radiation Database (NSRDB) data from 2018 [17] to obtain solar radiation data based on the location of the PV module. It should be noted that the 2018 NSRDB data does not include the solar azimuth data, thus the azimuth angle has been extracted from the 2010 data [37] to use in this work. The solar zenith values of the two years are consistent and similar, thus the 2010 solar azimuth angle seems to be appropriate to be used in combination with 2018 data[17]. This numerical project models the existing PV module installed at the Cali- fornia State University, Los Angeles, shown in Figure 2.2. The module has a surface area of $A = 1.635m$ with a characteristic length of $L = 1.651m$, width of $w = 0.991m$,and thickness $t = 0.0381m$. The module also has a default tilt angle of $\alpha = 34^{\circ}$ and a default solar azimuth angle of $\theta Az = -11.9^{\circ}$. The module has a reference efficiency of $\eta ref = 12\%$, and a power temperature coefficient of $\zeta = 0.0045\%/^{\circ}C$. The emissivity and absorptivity of the module are assumed to be $\epsilon = 0.85$ and $a = 0.85$, respectively. Table 1 lists physical parameters used in the numerical simulations.

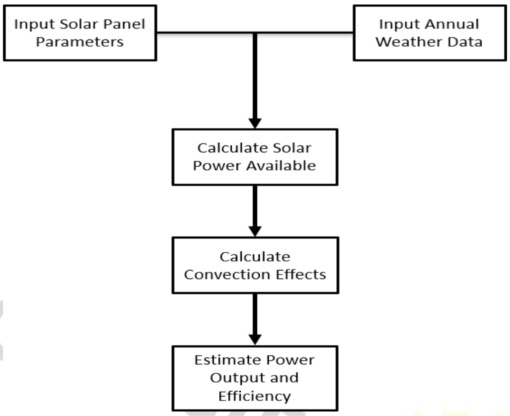

Figure:Numerical Model Flow Chart

thermal model, and solar data. This model is used to test different configurations with natural convection and forced convection, to show how much effect wind flow has on the PV performance. This work considers two cases which will be presented in the next section. The first case (Case A) considers a fixed PV module orientation with varying wind speed and direction; the second case (Case B) considers varying tilt angle, wind direction, and wind speed.

Since the administering conditions and the mathematical technique have been introduction duced, this segment presents the outcomes from the mathematical recreations. The simula-tion are led utilizing NSRBD 2018 sunlight based information assumed control more than one year and in hourly stretch, and is expected to have steady wind speed and wind heading. Wind di-rection in these outcomes is indicated as γ (yaw point), which is the point between the approaching breeze comparative with the PV module. This information is then used to decide the yearly average force yield and the proficiency of the PV module, in various contextual investigations. The outcomes are separated to two contextual analyses, and are introduced in the accompanying subsections.

Case A: Effects of Wind Speed and Yaw Angle

This section presents the results of the case study in which wind speed and yaw angle are varied to study the convective effects on power production. In this case, the PV module is fixed, with an azimuth angle of -11.9◦ and a tilt angle of 28◦. The purpose of having these angles fixed, is that it reduces the number of variables, so that it is possible to observe how wind flow affects the performance of the PV module at different speeds and yaw angles. This case observes the wind effects at wind speeds of 0.5, 1.5, 3.0, 7.0, and 9.0 m/s and yaw angles of 0◦, 30◦, 60◦, and 75◦. These results are compared to a case that does not consider convective effects, with a fixed PV temperature of 40◦C, referred to as fixed temperature case (FTC).

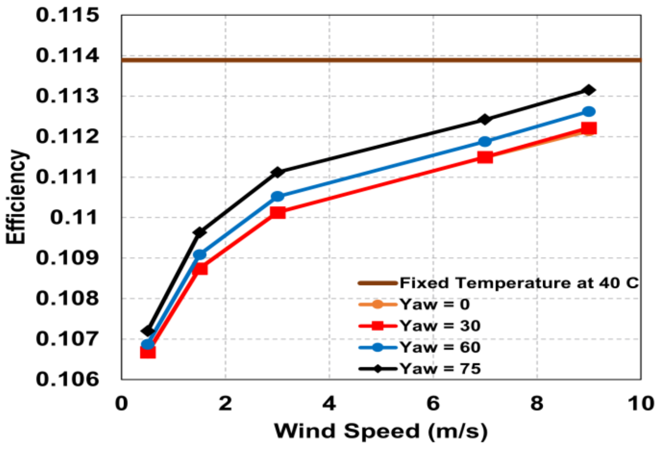

Figure : Average PV efficiency at different wind speeds and yaw angles.

points, and Figure shows the normal force yield at various breeze paces and yaw points. From these figures, it very well may be seen that the force and productivity increment fundamentally as wind speeds increment from 0.5 m/s to 3.0 m/s, at approxi-mately 6% expansion in power yield in this reach. Be that as it may, at higher breeze speeds the expansions in power yield and effectiveness are less critical, with around 3% increment in power yield when wind speed increments from 3 m/s to 9 m/s. Furthermore, at low wind speeds yaw point doesn't significantly affect power yield and effectiveness. Notwithstanding, at higher breeze speeds (3 to 9 m/s), yaw points do have a more articulated impact, with bigger yaw points beating more modest ones. It is notewor-thy to specify that outcomes at 0◦ and 30◦ yaw are indistinguishable. Moreover, for the case where the temperature is fixed at 40◦C, it tends to be seen that the force yield is steady and since the warm impacts are not considered, the equivalent can be found in productivity too. By noticing these outcome, it shows that the force. output and efficiency are greatly overestimated and that the PV module performance is not constant, when wind effects are considered. The next subsection will present the second case study on the effects of tilt angle.

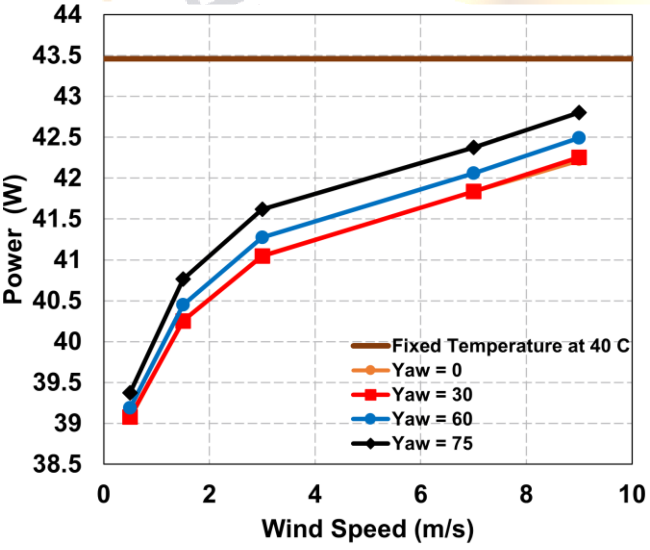

FIGURE: AVERAGE ANNUAL POWER AT DIFFERENT WIND SPEEDS AND YAW ANGLES

Case B: Effect of Tilt Angle Considering Wind Effects

In this case, the slant point is changed. Like case A, the azimuth point is fixed at - 11.9◦; notwithstanding, the slant point is fluctuated between 10◦ to 80◦. The slant point (α) is depicted as the approach of the PV module comparative with the approaching level breeze, as displayed in Figure 2.1. The ideal slant not really settled considering both breeze stream and sun oriented irradiance, which might vary than when just sun based irradiance is thought of. Simultaneously, the yaw point and wind speed will shift in a similar reach as in the event that A, however for this situation, the slant point will be changing too. The outcomes will then, at that point, be plotted close by the FTC case, similarly as in the last subsection.

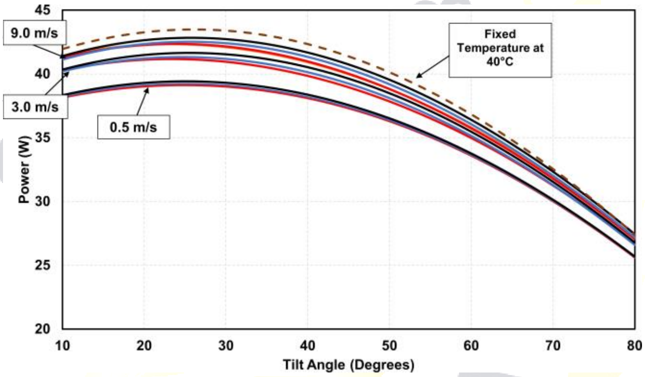

Figure : Average annual PV power with lines of constant yaw angle and wind speed, with varying tilt angle.

IV . RESULTS

This Later examinations have zeroed in on creating models to catch the impacts of slant point, wind heading, disturbance force, sun oriented irradiance, surrounding gum based paint ture on surface temperature, and along these lines, PV execution utilizing displaying and experimentation. Mahboub et al. [15] concentrated on the impacts of slant point on convective hotness move coefficient and fostered another experimental condition dependent on experi-mental and computational liquid elements (CFD) results. Iakovidis and Chime [22] led air stream tests to evaluate the impact of disturbance force on nearby and normal hotness move coefficients. Therefore, a field test by Vasel and Iakovidis [12] presumed that breeze heading significantly affects the creation yield of a PV sunlight based plant. The format of lines of PV exhibits can sig-nificantly influence the violent force as wind streams through the PV plant. Wu et al. [21] directed air stream trials and CFD reproductions to concentrate on the temperature conveyance on a PV module, and the aftereffects of this work were utilized by Ghabuzyan et al. [16]. It was discovered that breeze stream added to an expansion in heat move on PV modules, accordingly prompting more prominent creation. Ogundimu et al. [17] investigated how sun based module direction and slant point can be upgraded to augment sun oriented radiation gathering. Besides, Bhattacharya et al. [28] and Mama et al. [19] presumed that sun powered irradiance and surrounding temperature are key contributing variables that influence PV execution. It is fascinating to take note of that Mama et al. analyzed different numerical models to survey the capacity to precisely anticipate the surface gum based paint ture of a sun powered module under fluctuating natural conditions. They presumed that breeze speed didn't assume a huge part in sun powered module effectiveness. Various warm models have been created to gauge the impact of hotness load on temperature, and thusly, the energy yield. Goverde et al. [10] per-shaped air stream tries that demonstrated that the spatial temperature varia-tions brought about by wind ought to be considered for precision yield assessment. Prilliman et al. [11] then fostered a quick transient warm model that records for transient climatic conditions and warm mass of module, which further develops energy creation expectation. Coskun et al. [12] proposed new connections dependent on exploratory information while representing varieties in irradiance, wind speed, and surrounding temper-ature. These connections can be utilized to anticipate the presentation of PV frameworks. As recently referenced, albeit summed up models stay tricky, new relationships dependent on solid exploratory information should be created as PV turns out to be all the more broadly embraced and coordinated with complex stream systems and building structures. This work expects to concentrate on a level rooftop mounted PV exhibit on a modern structure to analyze how wind speed, wind heading, and surrounding temperature influence cluster temperature and creation effectiveness. Another experimental connection fit is proposed in this work, which isn't accessible in the writing to the best of the writers' information. These trial results are then contrasted with CFD reenactments just as a current experimental model accessible in PVsyst, an industry-standard PV configuration bundle. The rest of the part is organized as follows: Area 3.2 portrays the exploratory arrangement; Segment 3.3 examines the warm model utilized in PVsyst; Segment 3.4 spotlights on the CFD model; and Segment 3.5 sums up the trial and mathematical outcomes in Subsections 3.5.1 and 3.5.2, separately.

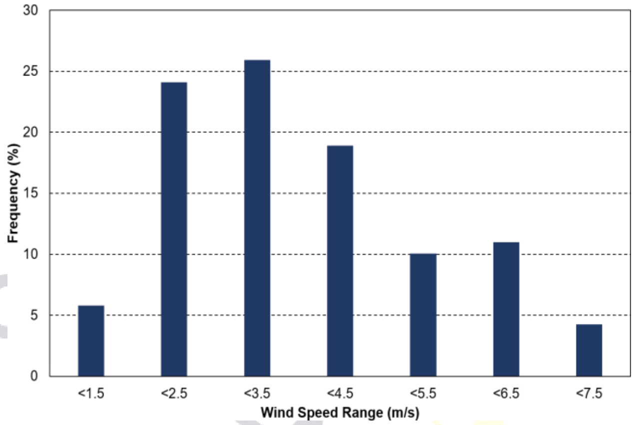

Figure : Wind speed histogram.

Figure delineates the histogram for temperature in the long periods of interest. As we are centered around the months without snowfall and from first light to nightfall, recorded temperatures lie somewhere in the range of 15oC and 35oC. It is notable that encompassing temperature significantly affects exhibit temperature, which thusly influences PV execution, and the information gathered in this work are utilized to evaluate the impacts of cluster effectiveness and surrounding temperatures.

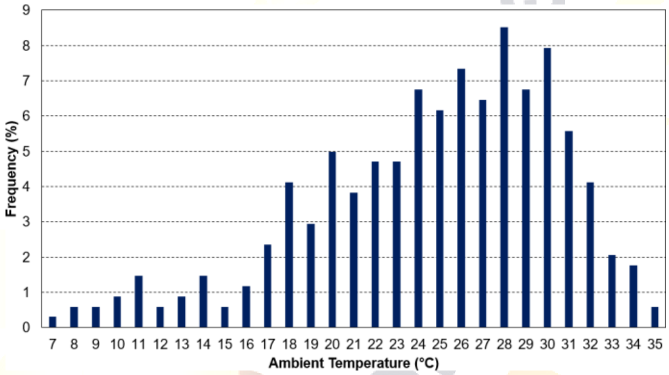

Figure: Ambient temperature histogram.

Figure shows the electrical transformation proficiency versus cluster temperature. Effi still up in the air utilizing estimated AC power yields and plane of exhibit irradiance. In controlled lab tests, PV proficiency diminishes directly with temper-ature. Each point in Figure 3.6a shows the hourly normal incentive for proficiency and temperature during the time of interest. There is a reasonable general pattern that as exhibit temperature diminishes, the productivity increments. In any case, as the temperature dips under 10oC, we saw a huge drop in proficiency; this is because of climate occasions like downpour. We then, at that point, separated the degree of sun oriented irradiance into three lev-els, low (Figure 3.6b, 100W/m2 to 399W/m2), medium (Figure 3.6c, 400W/m2 to 699W/m2), and high (Figure 3.6d, 700W/m2 to 1100W/m2). This gathering permits us to segregate bright climate to concentrate on the impacts of wind on power creation. In every one of the three groupings, we see close straight patterns between exhibit temperature and proficiency.

V CONCLUSION

As sun powered energy turns out to be increasingly famous, amplify its effectiveness and see what various conditions mean for gadget execution. The primary focal point of this work was to see how warm impacts change dependent on various conditions and how they impact the presentation of PV modules. Section 2 features that breeze stream impacted the exhibition of PV modules, which was more subject to wind speed instead of wind course. Along these lines, wind stream ought to be represented while deciding the ideal situation of the module. Be that as it may, wind stream didn't influence the ideal slant point choice, which stayed steady all through all wind rates and wind headings. Part 3 inspected the impact of environmental conditions on the PV power yield by concentrating on a PV cluster mounted on top of the CanmetENERGY; the outcomes feature that the PV exhibit delivered power with a higher effectiveness and lower surface surrounding temperature. Wind heading didn't influence the temperature of the exhibit, in light of the trial results. CFD recreations were directed dependent on this arrangement, which tracked down that the temperature profile fluctuated extraordinarily at lower wind speeds; nonetheless, it was more steady at higher breeze speeds. Section 4 concentrated on the impacts of having heat modules pair and changing their dividing; it was tracked down that the presence of couple modules prompted more noteworthy cooling on the downstream module and prompted more prominent warm convection, notwithstanding the dispersing of the modules.

REFRENCES

[1] Carlisle, J. E., Kane, S. L., Solan, D., and Joe, J. C., 2014. “Support for solar energy: examining sense of place and utility-scale development in california”. Energy Research & Social Science, 3, pp. 124–130.

[2] Hernandez, R. R., Easter, S., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., Ravi, S., et al., 2014. “Environmental impacts of utility-scale solar energy”. Renewable and sustainable energy reviews, 29, pp. 766–779.

[3] Cao, X., Dai, X., and Liu, J., 2016. “Building energy-consumption status world- wide and the state-of-the-art technologies for zero-energy buildings during the past decade”. Energy and buildings, 128, pp. 198–213.

[4] S¸en, Z., 2004. “Solar energy in progress and future research trends”. Progress in energy and combustion science, 30(4), pp. 367–416.

[5] Omubo-Pepple, V., Israel-Cookey, C., and Alaminokuma, G., 2009. “Effects of temperature, solar flux and relative humidity on the efficient conversion of solar energy to electricity”. European Journal of Scientific Research, 35(2), pp. 173–180.
put performance”. International Journal on Advanced Science, Engineering and Information Technology, 6(5), pp. 682–688.

[6] Cox Iii, C., and Raghuraman, P., 1985. “Design considerations for flat-plate- photovoltaic/thermal collectors”. Solar energy, 35(3), pp. 227–241.
Zondag, H., 2008. “Flat-plate pv-thermal collectors and systems: A review”.Renewable and Sustainable Energy Reviews, 12(4), pp. 891–959.

[7] Christensen, C., and Barker, G., 2001. “Effects of tilt and azimuth on annual incident solar radiation for united states locations”. Solar Engineering, pp. 225– 232.

[8] Yadav, A. K., and Chandel, S., 2013. “Tilt angle optimization to maximize incident solar radiation: A review”. Renewable and Sustainable Energy Reviews, 23, pp. 503–513.

[9] Armstrong, S., and Hurley, W., 2010. “A thermal model for photovoltaic panels under varying atmospheric conditions”. Applied Thermal Engineering, 30(11- 12), pp. 1488–1495.

[10] Mehleri, E., Zervas, P., Sarimveis, H., Palyvos, J., and Markatos, N., 2010. “Determination of the optimal tilt angle and orientation for solar photovoltaic arrays”. Renewable energy, 35(11), pp. 2468–2475.
Zhao, Q., Wang, P., and Goel, L., 2010. “Optimal pv panel tilt angle based on solar radiation prediction”. In 2010 IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems, IEEE, pp. 425–430.

[11] George, A., and Anto, R., 2012. “Analytical and experimental analysis of optimal tilt angle of solar photovoltaic systems”. In 2012 International Conference on Green Technologies (ICGT), IEEE, pp. 234–239.

[12] Schwingshackl, C., Petitta, M., Wagner, J. E., Belluardo, G., Moser, D., Castelli, M., Zebisch, M., and Tetzlaff, A., 2013. “Wind effect on pv module temperature: Analysis of different techniques for an accurate estimation”. Energy Procedia, 40, pp. 77–86.

[13] Tonui, J., and Tripanagnostopoulos, Y., 2007. “Air-cooled pv/t solar collectors with low cost performance improvements”. Solar energy, 81(4), pp. 498–511.

[14] Siecker, J., Kusakana, K., and Numbi, B., 2017. “A review of solar photovoltaic systems cooling technologies”. Renewable and Sustainable Energy Reviews, 79, pp. 192–203.

[15] Gokmen, N., Hu, W., Hou, P., Chen, Z., Sera, D., and Spataru, S., 2016. “Inves- tigation of wind speed cooling effect on pv panels in windy locations”. Renewable Energy, 90, pp. 283–290.

[16] Goossens, D., and Van Kerschaever, E., 1999. “Aeolian dust deposition on pho- tovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance”. Solar Energy, 66(4), pp. 277–289.

[17] Kaldellis, J. K., Kapsali, M., and Kavadias, K. A., 2014. “Temperature and wind speed impact on the efficiency of pv installations. experience obtained from outdoor measurements in greece”. Renewable Energy, 66, pp. 612–624.

[18] Wu, Y.-Y., Wu, S.-Y., and Xiao, L., 2017. “Numerical study on convection heat transfer from inclined pv panel under windy environment”. Solar Energy, 149, pp. 1–12, doi: 10.1016/j.solener.2017.03.084.

[19] [22] Iakovidis, F., and Ting, D. S.-K., 2014, doi: 10.1115/IMECE2014-36560. “Effect of free stream turbulence on air cooling of a surrogate pv panel”. In ASME 2014 International Mechanical Engineering Congress and Exposition, American Society of Mechanical Engineers Digital Collection.

[20] Jubayer, C. M., and Hangan, H., 2014. “Numerical simulation of wind ef- fects on a stand-alone ground mounted photovoltaic (pv) system”. Jour- nal of Wind Engineering and Industrial Aerodynamics, 134, pp. 56–64, doi: 10.1016/j.jweia.2014.08.008.

[21] Abiola-Ogedengbe, A., 2013. “Experimental investigation of wind effect on solar panels”.

[22] Mahboub, C., Moummi, N., Moummi, A., and Youcef-Ali, S., 2011. “Effect of the angle of attack on the wind convection coefficient”. Solar energy, 85(5), pp. 776–780, doi: 10.1016/j.solener.2011.01.008.

[23] Warsido, W. P., Bitsuamlak, G. T., Barata, J., and Chowdhury, A. G., 2014. “Influence of spacing parameters on the wind loading of solar array”. Journal of fluids and structures, 48, pp. 295–315.

[24] Aly, A. M., 2016. “On the evaluation of wind loads on solar panels: The scale issue”. Solar Energy, 135, pp. 423–434.

[25] Maz´on-Hern´andez, R., Garc´ıa-Cascales, J. R., Vera-Garc´ıa, F., K´aiser, A., and Zamora, B., 2013. “Improving the electrical parameters of a photovoltaic panel by means of an induced or forced air stream”. International Journal of Photoenergy, 2013.

[26] Trinuruk, P., Sorapipatana, C., and Chenvidhya, D., 2007. “Effects of air gap spacing between a photovoltaic panel and building envelope on electricity genera- tion and heat gains through a building”. Asian Energy Environ, 8(1), pp. 73–95.

[27] Skoplaki, E., and Palyvos, J. A., 2009. “On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power corre- lations”. Solar energy, 83(5), pp. 614–624.

[28] Wu, S.-Y., Wu, Y.-Y., Xiao, L., and Yang, Z., 2018. “Experimental study of natural convection heat transfer from a nonuniformly heated flat plate simulating pv panel”. *Journal of Mechanical Science and Technology*, ***32***(1), pp. 423–432, doi: 10.1007/s12206–017–1243–5.