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Evaluation of Climate Parameters and Energy Generation Potentials of Solar Powered Automatic Weather Station

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ABSTRACT: The current trends of information concerning the development, applications, dissemination and diffusion of solar energy resource and technologies is grossly inadequate and needs to be stepped up through researches. In this research, a weather station was design and assembled at the site of the Center for Renewable Energy Technology {CRET}, Federal University of Technology, Akure, Ondo State, Nigeria. The materials for the instrument includes a data logger with solar radiation sensor and an anemometer, wind vane, relative humidity sensor and air particulate matter sensors built within the instrument to track and record daily radiation and PV cell temperature. The equipment is powered by a 12 V, 45 AH Lithium battery.Inside the weather station are an integrated sensor suite {ISS} which is made up of solar panel temperature, relative humidity, wind speed and direction and solar radiation sensors installed to detect physical changes in the environment and output the parameters as digital signals into the signal conditioning circuits. This signal conditioning circuit manipulates the signals and prepares them for the next stage of processing. From the signal conditioning circuits, the data are sent to the central processing unit that interpret the data received from the sensors, stores them in the data memory, access them and uses instructions stored in its programme memory to decipher and apply the incoming data. Minitab statistical software was used for the data analysis, such as regression and the analysis of variance {ANOVA}. The result revealed that air temperature was in most cases higher than the panel plate temperature and both fluctuated throughout the day. The higher radiation intensity during the months of September 2023 and January 2024 accounted for the high temperature level recorded in the two months. The lowest relative humidity of 22% was recorded between the hours of 9 am and 12 noon and the highest solar radiation of 6000 Wm^2were recorded between the same hours. Also, a 2.3 watts power was generated at these same hours of the day. The result revealed that the highest air temperature of 27.45 ^{0}C was observed in the month of November and the average relative humidity of 99.6% observed in the month of October. The average solar radiation data for the months of September2023 to January 2024 were obtained and the result revealed that out of the five months considered, December exhibited the highest average solar radiation level of 70.0 W/m^2 at between the hours of 9 am and 12 pm. The relationship between all the variables logged as it affects values of output current and power for the months of September 2023 and January 2024 were expressed in the regression equations.

Keywords: Solar radiation, Photovoltaic cell temperature, Power, Voltage, Current.

I. INTRODUCTION.

Renewable energy is energy generated from natural resources such as sunlight, wind, tides and geothermal heat which are renewable. There have been rigorous efforts to meet the global energy demand challenges but relying on the traditional fossil fuels alone is synonymous to taken a great risk of backward trend in modern developmental strategies {Devaux, 2013}. The main reason behind this assertion is that fossil fuels and other conventional energy resources are not only limited but their global reserves is declining as each day closes. Excessive combustion of fossil fuel for energy has potential contribution to negative environmental consequences such as global warming. To this end, renewable energy has attracted a very realistic global interest being the only viable option available to man for providing solution to energy {Bohringer et al, 2013}. Accelerating the deployment of renewable energy will fuel economic growth, create new employment opportunities, enhance human welfare and contribute to a climate safe future. Advances in renewable energy technologies and growing cost-competitiveness have strengthened the business case of renewable and opened new opportunities for countries to transform their energy systems. AEE {2015} asserted that renewable energy could provide as much as 35% of the world's energy needs by 2030, given the political will to promote its large scale deployment in all sectors on a global level, coupled with far reaching energy efficiency measures. Irene {2013} reported that by choosing renewable energy and energy efficiency, developing countries such as Nigeria can virtually stabilize their CO_2 emissions whilst at the same time increase energy consumption through economic growth. Meteorological data plays an important role in evaluating the power generation efficiency and feasibility of solar power projects {Saglam, 2010; Gopi et al., 2021} analyzed and modeled the weather impact of a utility-scale PV power plant in the tropical region. In the results of the study, a regression model of the amount of solar energy for all weather seasons was generated based on different weather parameters. Sadio et al., {2017} used weather information {wind speed, ambient temperature, and solar radiation} to determine the availability of solar power at Ngoundiane's site. Alskaif et al., {2020} analyzed various meteorological variables, including temperature, relative humidity, visibility, air pressure, wind speed, cloud cover, wind power, precipitation and evaluated their impact on photovoltaic {PV} power output. In Kuchler {2013} study, weather parameters were collected to simulate solar power station at the University of Surabaya, Indonesia. The results of the weather data collection showed that there was a discrepancy between satellite data and the set up weather station for data collection. Therefore, the data of the set up station helped to determine the amount of solar power more accurately.

Low photovoltaic {PV} panel efficiency has been linked to a number of parameters, including canopy coverage, shade, dust, particle matter setting, temperature and solar radiation according to Inwanto et al.{2014} and Bhol et al., {2015}. According to Karafil et al.{2016}, the effects of temperature and solar radiation on the performance of photovoltaic cells are more pronounced. Solar radiation has an impact on the performance of PV cells {Bong et al., 201}. A drop in solar radiation automatically causes solar panels to loose electricity while an increase in the surrounding temperature causes photovoltaic cells to operate less efficiently {Karafil et al., 2016}. According to a study by Omubo-Pepple et al., {2013} on the impact of climatic factors on solar panel performance, solar flux determines PV efficiency and current output and relative humidity lowers the current output of a solar panel array. The accumulation of dispersed particulate matter on solar panel surfaces, presents another drawback in regions with solid mineral exploration and pollutant emission. Also the study by Omubo-Pepple et al., {2013} on the effects of meteorological variables on the performance of solar panels indicates that current output and the efficiency of PV are dependent on solar flux and that relative humidity causes a decline in the current output of an array of solar. The impact of the environment on the functionality of photovoltaic cells has been the subject of several researches {Amusa et al, 2021}. Overall, their research concluded that the PV's ability to produce energy is influenced by the sun's intensity. Generally, weather and environmental factors have a significant impact on effectiveness and power yield from a network of solar panels {Nwokocha et al., 2013}

Renewable energy has gained so much attention among other sources of energy due to the several advantages related to its use. The use of energy for the generation of electricity has gained attraction recently due to the plummeting cost of its components. {Qaisrani et al., 2019}. Solar energy which is a renewable source of energy is ranked among the rapidly rising source of energy in the world, due to its pollution free, noiseless and clean nature. Due to the depletion of the ozone layer and global warming, solar energy is receiving huge attention. {Njok et al., 2020a}.Despite the several literatures on the effect of climate change and consequent use of renewable energy technologies, there have been limited studies on the area of obtaining data for assessment on climate parameters and sustainability of energy derived from renewable solar energy systems. There is therefore the need for an accurate understanding of how these climate parameters affect renewable energy generation and sustainability. This study investigates climate parameters that directly affect energy generation from solar power in Akure, Ondo State.

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II. MATERIALS AND METHODS

2.1 Experimental Set Up.

. The pilot study was carried out at the Centre for Renewable Energy Technology {CRET} Federal University of Technology Akure, the capital city of Ondo State, and South-West Nigeria. Akure is located within the humid region of Nigeria. The city lies within latitudes $7^0$14'N and 7^0 17'N and within longitudes $5^0$08'E and $5^0$13'E. The climate of the study site is humid sub-tropical, with an annual rainfall of 1300-1600 mm and a mean temperature of 27^0C {Fasinmirin et al., 2018}. The relative humidity varied from 85% to 100% in the wet season but less than 60% in the dry season {Fasinmirin and Adesigbin, 2012}.

A weather station was design and assembled at the site of the Centre for Renewable Energy Technology {CRET}, Federal University of Technology, Akure, Ondo State, Nigeria. The materials for the instrument includes a data logger with solar radiation sensor, an anemometer wind vane placed on an iron stand which was firmly positioned on the ground in a fixed position and at an orientation to receive sunlight from all directions. It is powered by a 12V, 45 AH Lithium battery. Air irradiation sensors, relative humidity sensor and air particulate matter sensors of various sizes ranging from 1.0, 2.0 and 10.0 were built within the instrument to track and record daily radiation and PV cell temperature. Under the prevailing meteorological conditions, the temperature {above} and temperature (below) the PV panel, air pressure, relative humidity and particulate matter of various sizes, wind speed, wind direction, solar radiation and current produced by the PV panel were measured.

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III. RESULTS AND DISCUSSIONS.

The instrument constructed was used in the field experimentation. It was primarily built as a digital processor in a small portable case with a Lithium battery of 12 V 45 AH to supply the current. It was made up of electrical cables, internal memory storage, sensors and a programmable module which takes data as a stand-alone device. The instrument was stationed at a strategic position at the Centre for Renewable Energy and. was configured to capture weather data automatically for five months duration from September, 2023 to January, 2024. Data acquired include: temperature of the top and bottom of the solar panel displayed in degree centigrade {^{0}C}, the air temperature in degree centigrade {^{0}C}, the pressure in {mbar}, the relative humidity {RH} in percent, particulate matter {PM} in parts per million {ppm} particulate matter PM 2.5 in parts per million and PM 10 in parts per million {ppm}; the solar radiation {Wm^{-2}} and the wind speed in meters per seconds {m/s}. The instrument also recorded the solar voltage, solar current and power generated in watts. The readings were taken with a memory card. The data obtained from the instrument were directly down loaded from data logger to computers laptop.

3.1.1Analysis of Panel Surface and Air Temperatures.

Figure 3.1 shows the plot of the measurements mode on panel surface and air temperatures with respect to 24 hours of the day for the months of September 2023 and January 2024 with the aim of establishing the effects of air and surface temperature profile of the entire 24 hours of the day throughout the months under consideration and its effect on the environment. Results showed that the air temperature was in most cases higher than the panel top temperature and both fluctuated throughout the day. The highest air temperature of 43^0C was recorded in the morning between the hours of 9 am and 12 pm while the lowest air temperature of 23^0C was recorded between the hours of 6pm and 8am. Also the highest panel temperature of 40^0C was recorded between the hours of 12 pm and 6pm while the lowest panel temperature of 21^0C was recorded between the hours of 6pm and 8am.This is close with the average Futa Satellite readings taken over ten years to be 25.3 ^{0}C.

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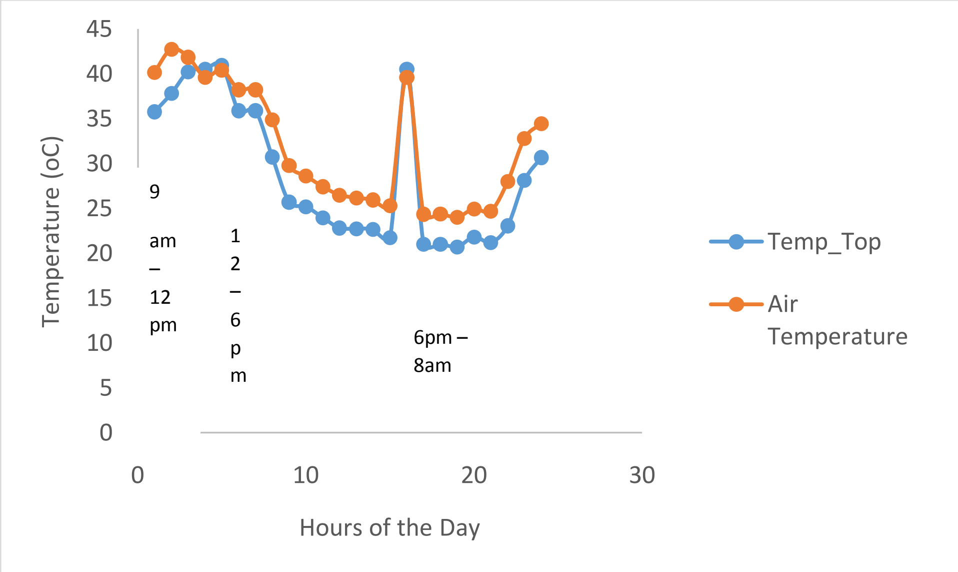

Fig 3.1: Air and Panel temperature at various hours of the day

3.1.2The plot of measurements with respect to relative humidity showed that the relative humidity was lowest at 25% between the hours of 9am and 12pm and highest at 90% between the hours of 6pm and 8am as illustrated in the Figure 3.2. The results of the developed instument agrees closely with the studies of Akinbode el al {2001} who reported relative humidity {RH} values ranging from 39% to 98.2% across different stations and times in Akure with annual mean around 76.9%..

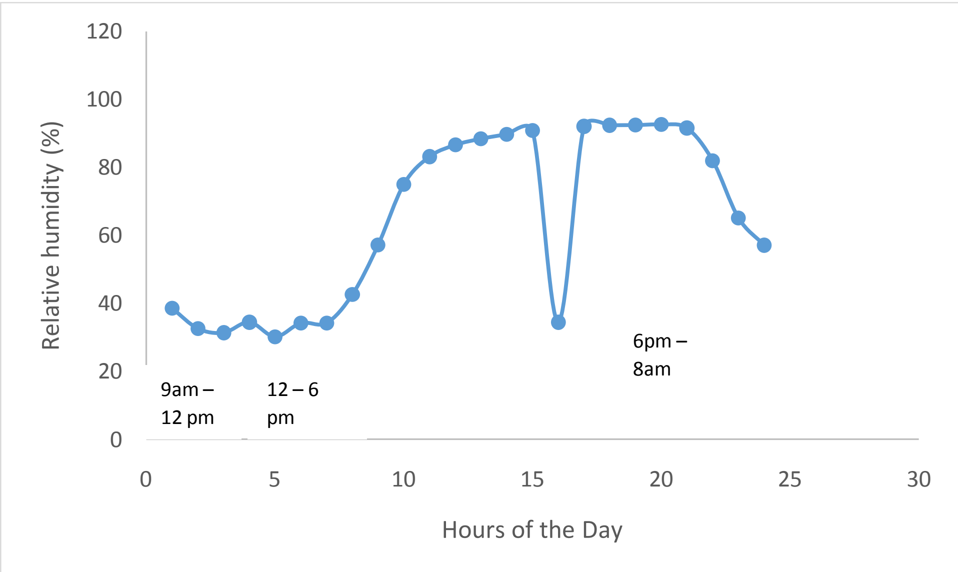

Fig 3.2 Relative humidity at various hours of the day

3.1.2The plot of solar radiation shows flunctuations in the trends. Solar radiation is highest in the morning at 6000Wm^{2}between the hours of 9 am and 12 pm and lowet at 5100 Wm^2 between the hours of 12 pm and 6 pm and rises again to 5900 Wm^2 at between the hours of 6 pm and 8 am. This is as a result of the supply of current that was stored in the battery during the day. Figure 3.3 also show
s that as early as 8:30 am maximum voltage could be expected from the photovoltaic module.

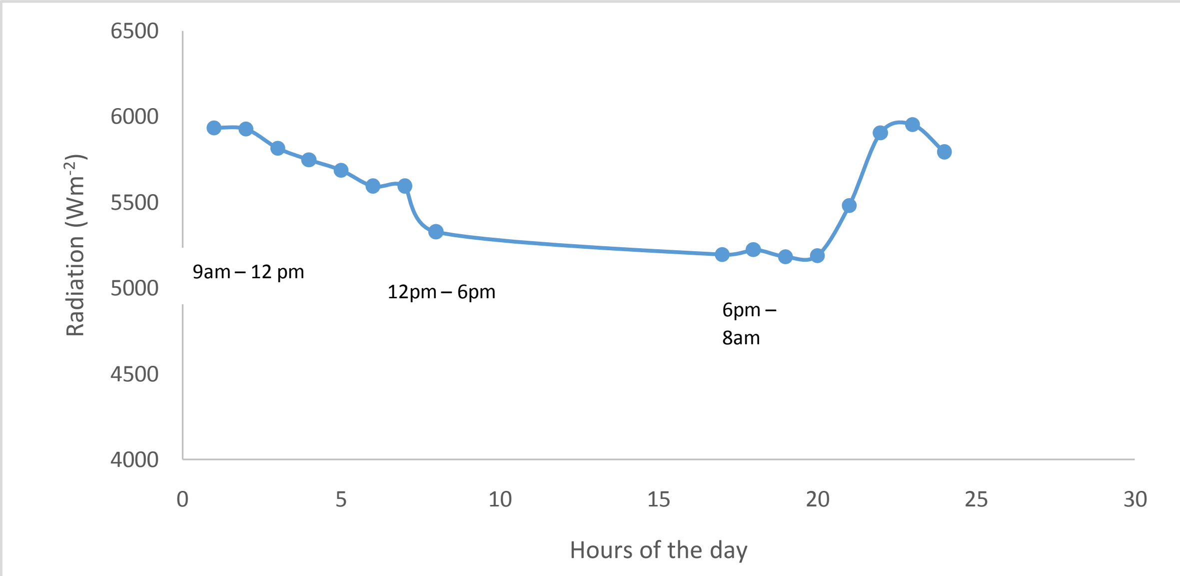

Fig.3.3: Solar Radiation at various hours of the day

3.1.4 The plot of the wind speed on function of the hours of the day is presented in figure 3.4The wind speed shows a rise and fall pattern at the experimental location. The highest wind speed of 1.06 m/s was recorded between the hours of 9am and 12pm while the lowest wind speed of 0 m/s was recorded between the hours of 6pm and 8am. The wind speed is close to the average Futa Satelite readings of 1.09 m/s taken over ten years period.

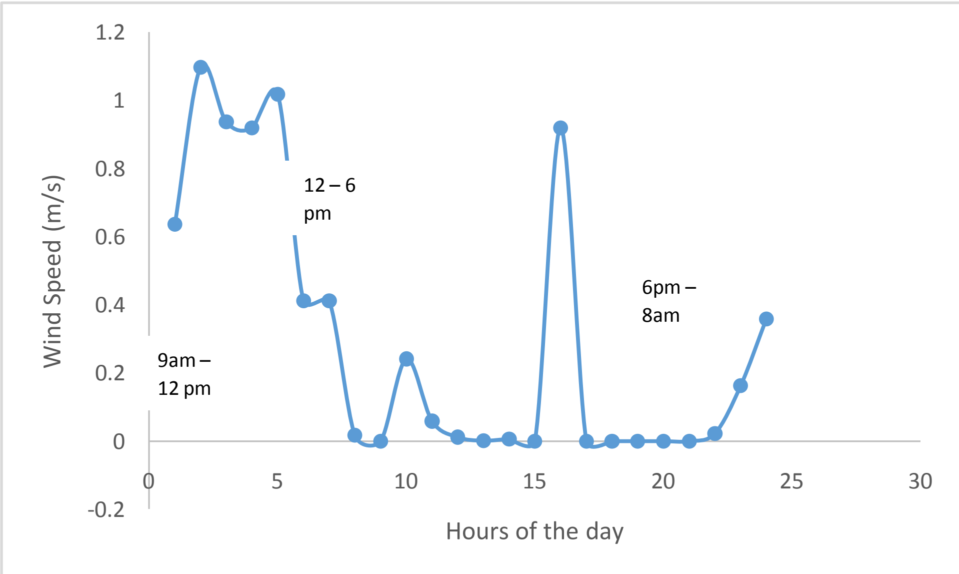

Fig: 3.4: Wind Speed at various hours of ther day

3.1.5 Particulate or atmospheric matter are microscopic particles of solids or liquid matter suspended in the air. PM 1.0 are extremely fine particulates with a diameter of fewer than 1 microns. PM 2.5 have diameter of less than 2.5 microns. PM 10.0 means the particles have a diameter less than 10 microns or 100 times smaller than a millimeter. The accumulation of particulate matter layers on the PV module surface is one of the operating environmental factors that cause

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significant reduction in PV system performance. Consequently, it leads to power loss, reduction of service life and increase in module temperature.

PM 10.0 recorded the highest at 65 ppm {parts per millio} followed by PM 2.5 at 60 ppm and PM 1.O at 35 ppm, all of them at between the hours of 6pm and 8am. However PM 1.0 recorded the lowest at 20 ppm between the hours of 6 pm and 8 am. {Muhammad et.al., 2022} corroborated this results in their work when they recommended that the negative impact of particulate matter on the performance of the PV system should be considered carefully during the decision-making process of setting solar energy generation targets in the regions with a high level of particulate matter.

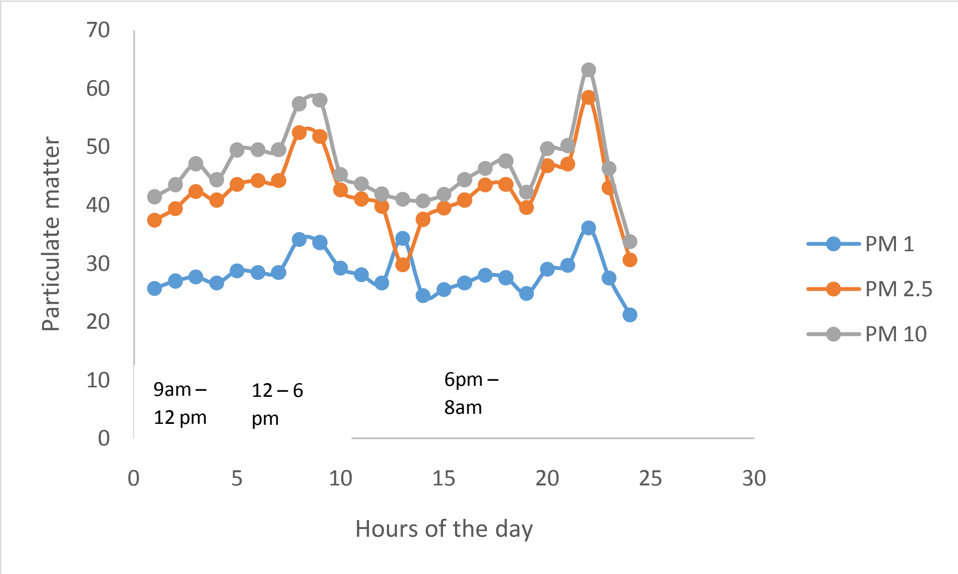

Fig. 3.5: Particulate Matters at various hours of the day.

3.1.6 The graph of the power generated with respect to the hours of the day as presnted in figure 3.6 The highest power of 2.3 W generated was between the hours of 9am and 12 pm and the lowest power generated was between the hours of 6pm and 8 am. This positive effect of solar power on the efficiency is as a result of the favourable effect that increasing solar power has on current and it agrees with earlier research by {Njok et. al., 2018}.

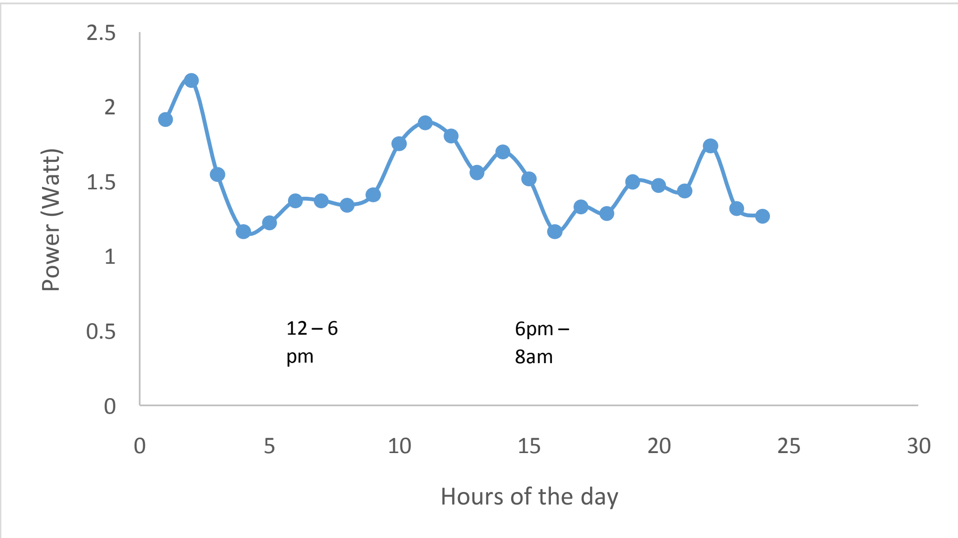

Fig. 3.6: Power generated at various hours of the day.

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IV. MODELLING RESULTS

Power output is directly proportional to the inputs. The output is the dependent variable and the inputs are the independent variables. This relationship is of the form taken by the multiple linear regression model. We are aware that there are some errors to be minimized in the development of the model and this inform the choice of multiple linear regression model where the error is minimized while estimating the parameters of the model. The test on the parameters of the model shows the relevance of each of the meteorological variables to solar output.

Table 4.1: Regression Analysis: Panel Current (A).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	6	0.000447	0.000075	95.19	0.000
AT	1	0.000001	0.000001	0.66	0.426
PR	1	0.000016	0.000016	20.66	0.000
RH	1	0.000034	0.000034	43.01	0.000
SR	1	0.000035	0.000035	44.34	0.000
WS	1	0.000043	0.000043	55.28	0.000
UV	1	0.000001	0.000001	1.54	0.226
Error	24	0.000019	0.000001		
Total	30	0.000466			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0008851	95.97%	94.96%	93.59%

Regression Equation

Panel C(A) = 0.906 - 0.000166 AT - 0.000911 PR + 0.000193 RH + 0.000601 SR + 0.001163 WS + 0.00714 UV

From the analysis of variance [ANOVA} pressure, relative humidity, solar radiation and wind speed have significant effects on panel current {Amps} 95% level of significance.

Table 4.2: Regression Analysis: Power (watt).

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	6	0.012712	0.002119	87.99	0.000
AT	1	0.000022	0.000022	0.90	0.353
PR	1	0.000522	0.000522	21.68	0.000
RH	1	0.001171	0.001171	48.66	0.000
SR	1	0.001008	0.001008	41.85	0.000
WS	1	0.001772	0.001772	73.60	0.000
UV	1	0.000016	0.000016	0.65	0.426
Error	24	0.000578	0.000024		
Total	30	0.013289			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0049068	95.65%	94.56%	93.01%

Regression Equation

Power = 4.87 - 0.00107 AT - 0.00517 PR + 0.001140 RH (watt) + 0.003237 SR + 0.007442 WS + 0.0258 UV

The analysis of variance for power {watts} shows that pressure; relative humidity, solar radiation and wind speed have significant effects on power generated at 95% level of significance.

V. CONCLUSION

The study analyzed various meteorological variables, including temperature, relative humidity, air pressure, wind speed, solar radiation, particulate matters of various sizes and their impacts were evaluated on the photovoltaic {PV} power output of the constructed instrument.

The result revealed that air temperature was in most cases higher than the panel top temperature and both fluctuated throughout the day. The high sun intensity during the months of September 2023 and January 2024 was the reason for the high temperature level. The lowest relative humidity of 22% was recorded between the hours of 9 am and 12 pm and the highest solar radiation of 6000 Wm^2 was recorded between the same hours. Also the power of 2.3 watts was generated at these same hours of the day. The result revealed that the highest air temperature of 27.45 ^0C was observed in the month of November and the average relative humidity of 99.6%. observed in the month of October. The average solar radiation data for the months of September2023 to January 2024 were obtained and the result revealed that out of the five months considered, December exhibited the highest average solar radiation level of 70.0 W/m^2 at between the hours of 9 am and 12 pm.The correlation analyses of climatic variables from September 2023 to January 2024 using both the satellite-sourced and the in-situ datasets showed some good correlations for the relative humidity and temperature.

Analysis of variance {ANOVA} was used to show the effects of each of the various parameters on the power, voltage and current produced. Various predictions of power, current and top temperatures were carried out to determine the effects of theses parameters on power, current and top temperatures using p-value to determine their levels of significance and Coefficient of Correlation {R} and Coefficient of Determination {R^2] were used to determine the fitness of the regression models. Minitab statistical software was used for the data analysis, regression analysis and the analysis of variance {ANOVA}.

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Appendix1.

PLATE 1:The complete constructed weather measuring instrument.

Appendix 2

PLATE 2: Setting the Instrument.