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A Comprehensive Analysis of Solar Panel Performance and its Correlation with Meteorological Parameters: A Study Performed at Jwagal, Lalitpur, Nepal

by

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A THESIS REPORT
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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
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The undersigned hereby certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **" A Comprehensive Analysis of Solar Panel Performance and its Correlations with Meteorological Parameters: A Study Performed at Jwagal, Lalitpur, Nepal"** submitted by Sagar Raj Baral in partial fulfillment of the requirements for the degree of Masters of Science in Renewable Energy Engineering.

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ABSTRACT

This thesis seeks to undertake a complete investigation of solar panel performance in relation to climatic factors, with an emphasis on Jwagal, Lalitpur, Nepal. The study investigates the complicated interplay between solar energy generation and several climatic characteristics such as temperature, humidity, and solar radiation using rigorous data collection and analysis. The primary goal is to improve the efficiency and dependability of solar energy systems using educated insights generated from meteorological data.

This thesis investigates solar panel performance in relation to meteorological data in order to identify patterns, trends, and correlations that may be used to influence the design, installation, and maintenance of solar energy systems. The global need for renewable energy sources is expanding, thus it is vital to understand how weather patterns and solar panel efficiency interact. Experiment used a wide range of environmental characteristics, including irradiance, temperature, and humidity, and their influence on solar panel performance.

The work uses advanced statistical methodologies and data analytics technologies to give vital new insights into the dynamic correlations between solar panel production and environmental parameters. This data may be utilized to create prediction models and optimization strategies that improve the efficiency of solar power generation. To establish which weather circumstances have the most influence on solar panel performance, patterns and trends in the data will be identified.

Results supports to develop a sustainable energy technology, opening the door for solar power to become a popular clean and renewable energy source. Policymakers, energy planners, and industry stakeholders may increase the practicality and scalability of solar energy systems in a variety of environmental scenarios by implementing the key suggestions outlined in the research findings. This project seeks to help the long-term growth of the renewable energy industry by connecting solar energy technologies with meteorological science.

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LIST OF ABBREVIATIONS

DNI -Direct Normal Irradiance

GHI - Global Horizontal Irradiance

KWh - for kilowatt-hour

IEAs- International Energy Agencies

IRENA- International Renewable Energy Agency

IRR- Internal Rate of Return

LCOE- Levelised Cost of Electricity

MPP -Maximum Power Point

MPPT- Maximum Power Point Tracker

NOCT -Nominal Operating Cell Temperature

NREL -National Renewable Energy Laboratory

PV – Photo Voltage

CHAPTER ONE: INTRODUCTION

1.1 Background

Solar energy is radiation from the Sun that may produce heat, cause chemical processes, or generate electricity. The overall amount of solar energy incident on Earth is far greater than the world's present and projected energy needs. If properly exploited, this widely distributed source has the ability to meet all future energy requirements. Solar energy has grown in popularity as a renewable energy source in the 21st century due to its limitless supply and nonpolluting nature, as opposed to the limited fossil fuels coal, petroleum, and natural gas. The Sun is an extraordinarily strong energy source, and sunlight is by far the most abundant source of energy received by Earth; nonetheless, its intensity at the Earth's surface is rather modest. This is primarily because of the extensive radial dispersion of radiation from the distant Sun. The Earth's atmosphere and clouds absorb or scatter up to 54% of incoming sunlight, contributing to a slight additional loss. The sunlight that reaches Earth consists of roughly half visible light, 45% infrared radiation, and small amounts of ultraviolet and other types of electromagnetic energy..

Other solar-powered devices include solar cookers, solar heaters, and solar cells. Solar cookers are considered one of the most innovative cooking methods in use today. They are an excellent alternative to traditional fuels like gasoline, kerosene, and firewood. Solar cookers are an eco-friendly and cost-effective way to cook. Solar heaters can also be used to heat water using solar energy, eliminating the need for electricity. One of the biggest benefits of solar energy is that it's renewable and will be available as long as the Sun exists, for about another five billion years. This makes it a valuable resource for everyone. Additionally, using solar energy can reduce electricity costs and decrease our reliance on non-renewable sources like petroleum and coal. Solar energy can be used for various purposes, including generating electricity and heat, especially in areas without access to an electrical grid. It is also a cleaner source of energy.

1.2 Problem Statement

The phrase "reliable and modern energy" refers to energy derived from renewable resources, such as solar photovoltaics (PV), wind, geothermal energy, etc. In a country like

Nepal, where there are to 4-6 solar maxima and approximately 300 sunny days year, solar PV is very important (AEPC, 2021). Solar energy has become a viable option as people look more and more to renewable energy sources to lessen the effects of climate change. Wind speed, temperature, humidity, and sunshine intensity are just a few of the climatic factors that can affect how well solar panels operate and how efficient they are. To maximize energy production and improve the dependability of solar power systems, it is essential to comprehend the complex relationships that exist between various climatic elements and solar panel performance.

The efficiency of the solar panel is a major factor to determine the economic feasibility of a solar-powered power plant. Research conducted over the years has demonstrated that the various meteorological elements have a major impact on the efficiency of solar panels. Consequently, a connection that explains the relationships between the efficiency and various meteorological data is desperately needed. An attempt has been made to examine the impact of different climatic characteristics on efficiency in this study, and a correlation between them has then been suggested.

Thus, in order to find patterns, trends, and correlations that can guide the design, installation, and operation of solar energy systems, this thesis will undertake a thorough research of solar panel performance in relation to meteorological data. The results of this study will close this research gap, promote the development of sustainable energy technology, and ease the widespread use of solar energy as a clean, renewable energy source.

1.3 Objectives

1.3.1 Main objective

To conduct a comprehensive analysis of solar panel performance and its correlations with meteorological parameters to enhance the understanding of how weather affects solar energy production.

1.3.2 Specific objectives

- To Evaluate the performance of solar panels under various weather conditions, including solar radiation , temperature, and humidity.
- To identify patterns and trends in data to identify meteorological conditions that affect solar panel performance most significantly.
- To assess the impact of meteorological factors on solar energy system design, installation, and operation along with proposing solutions to improve performance and dependability.
- To Provide Recommendations for policymakers, energy stakeholders, and renewable energy specialists to use meteorological knowledge to enhance solar energy technology and promote wider adoption.

1.4 Limitations

Solar panel performance can be influenced by site-specific factors such as shading, orientation, tilt angle, and other local environmental conditions. These factors may not be fully accounted for in the analysis, potentially limiting the generalizability of the findings.

1.5 Organizations of Report

This report consist of five chapter which covers the solar pv performance with meteorological changes and their correlations . Chapters along with their main features are mentioned below .

Chapter 1: Introduction

This chapter one includes the information about solar panel parameters their significane on performances ,problem statement and objectives of the research/thesis.

Chapter 2:: Literature review

Theories along with previous researches related to this thesis are explained in this chapter. It focuses on comprehensive analysis and understanding and harnessing solar energy effectively.

Chapter 3: Methodology

This chapter demonstrates the research methods used to accomplish the goals of the study.The processes softwares and tools used for this research are explained here.

Chapter 4: Results and Discussion

The results of the activities carried out within the research frame, such as data collection, trend analysis, regression analysis, and correlation analysis, are shown in this chapter. The chapter also covers the justification and confirmation of the results.

Chapter 5: Conclusion and Recommendation

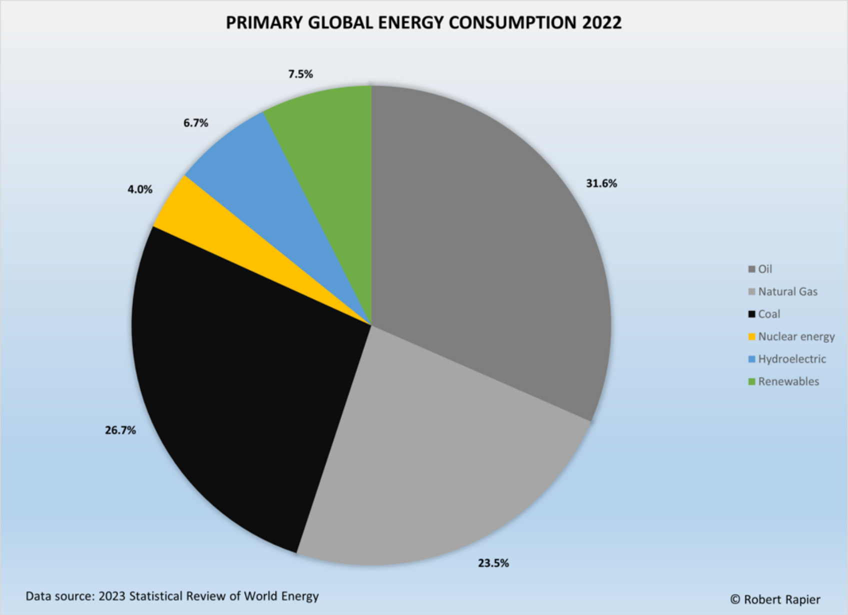
This chapter represents the conclusion of the targeted objectives of the topic in solar pv performances along with meteorological correlations. Recommendations for the further use and ways are provided.

Annexes contain the solar pv experiment data, panel installation photographs ,location and measurement photographs.

CHAPTER 2: LITERATURE REVIEW

2.1 Solar Energy

Without a question, the world's most plentiful resource is solar energy. It sets the stage for an extremely bright future in the next decades for the productions of cheap, clean, and highly sustainable energy (IEA 2011). (Howels 2016) clearly illustrates, the solar energy derived from the sun is significantly larger then the yearly energy consumptions of human. In addition, the graphic illustrates the potential of alternative accessible energy sources in relation to the yearly world energy consumption. According to the calculation, hydropower could only supply the world's primary required energy needs for a single year, whereas solar irradiation on all of the worlds be equal to 1800 more times that amount.



Source:2023 statistical Review of world energy consumption

Figure 1: Global total Energy Consumption

Maximum rated power (Pmax)

Maximum rated power (Pmax) is the maximum amount of power that a device or system can safely manage or output under specific operating circumstances without causing damage or failure. This rating is critical in many sectors, including electrical engineering, electronics, and renewable energy systems, since it assures the safety, dependability, and efficiency of the equipment.

Maximum Power point Voltage (Vmpp)

The Maximum Power Point Voltage (Vmpp) is the voltage at which a photovoltaic (PV) solar panel or array generates its peak power output. At Vmpp, the product of current and voltage is maximized, enhancing the solar panel's energy collection. Vmpp is critical for the efficient running of solar energy systems and achieving peak performance.

Maximum Power Point Current (Impp)

The Maximum Power Point Current (Impp) is the current at which a photovoltaic (PV) solar panel or array produces its peak power output (Pmax). This ideal current enables maximum efficiency and power output from the solar panel. Impp is an important criterion for optimizing energy collection in solar energy systems.

Open Circuit Voltage (Voc)

Open Circuit Voltage (Voc) is the greatest voltage that a photovoltaic (PV) solar panel can generate while no load is attached, implying that no current is flowing. Voc denotes the maximum voltage output from the panel under conventional test circumstances. It is an important characteristic in the design and optimization of solar energy systems, as it ensures compatibility with other components.

Short circuit current (Isc)

Short Circuit Current (Isc) is the highest current that a photovoltaic (PV) solar panel can generate when its output terminals are shorted, indicating that the resistance is close to zero. This value, evaluated under standard test circumstances (STC), shows the maximum current that the panel can deliver. Isc is critical for evaluating panel performance and constructing safe, efficient solar energy systems.

Tilt Angle

The tilt angle refers to the inclination of photovoltaic modules relative to the horizontal plane in a fixed, non-tracking mounting setup. It is generally advised to set this angle to match the latitude of the installation site for optimal performance.

2.1.1 Renewable Energy Context of Nepal

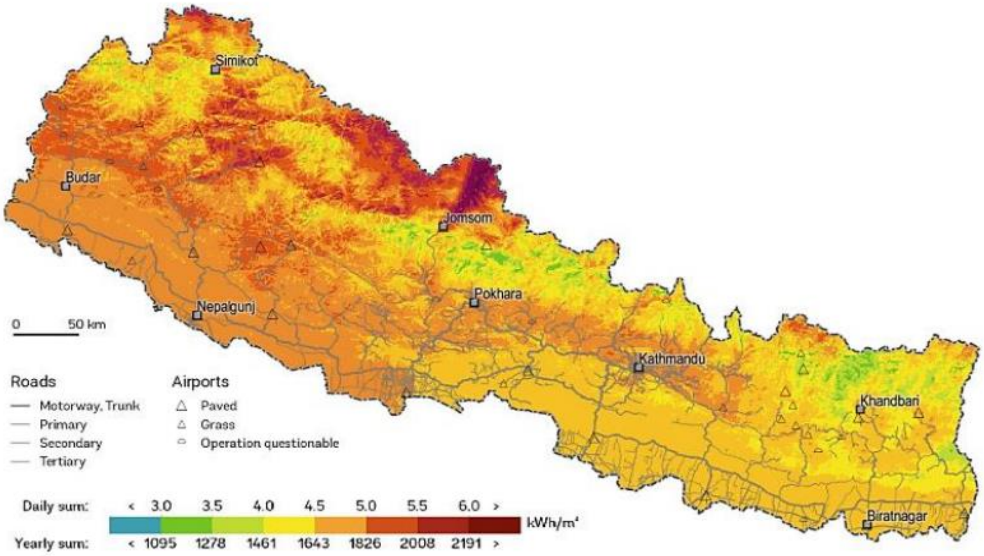
In Nepal, (GHI) can reach 5.5 KWh per m2 per day in the northwest while falling between 4.4 and 4.9 kWh/m2day in the south. The country's particular solar PV energy generation capacity ranges from 1400 to 1600 kWh per kWp (equivalent to an average in daily total of 3.8 - 4.4 kWh per kWp) (Synopsis Report of Nepal-energy sectors , 2022). Similarly, Kathmandu, Pokhara, Lukla, and Biratnagar had highest total solar irradiation of around 777.3, 816.0, 914.0, and 704.5 W/m2, respectively, with yearly average solar energy measuring 5.2, 5.4, 4.6, and 5.0 kWh per m2per day (Poudyel et al.,-2012). So, from this high solar energy output, it can meet daily needs, making it one of the greatest solutions in various sections of the country where the grid line is not connected. Furthermore, so in hilly region regions, this might be used to meet the daily required hot water requirements for everyday activities as well as for space heating.

Nepal is experiencing issues with power generation, transportation, and distribution systems. Currently, around 6.6 million Nepalese people do not have access to electricity, and those who do have access to the grid have interruptions (Miskat & Rashedi, 2021). Although 9% of households rely on off-grid renewable energy, the NEA reports that just 0.25% of total lands have solar PV conversion. With an energy efficiency of 20%, this is adequate to meet demand. Nepal still imports power, especially during the dry season. In 2017-2018, Nepal imported around 2.07 million liters of petrol, with demand expected to increase by 13.8% in the next year.

2.1.2 Solar Energy potential in Nepal

Solar photovoltaic (PV) offers significant potential in Nepal, as demonstrated by several research.The solar radiation impacting on Earth is approximately 1,366 J/s m2.Solar radiation intensity varies by location, with a typical value of 1000 w/m2 at sea level . During a clear day, the Sun emits 1.7x1022 J of energy at the earth's surface. This is comparable to three trillion barrels of total oil resources discovered on Earth. The annual energy usage is 4.6x1020 J, which is equivalent to one hour of sunlight. The sun's energy may be used in three major ways .Nepal has almost 300 sunny days each year. The Himalayan area does not get enough sun radiation to collect photovoltaic electricity year-round. Solar radiation averages between 3.6 and 6.2 kw/m2 each day. Solar energy generation is a viable option in Nepal. Although there is no confirmed history of sun harvesting in Nepal, a solar PV system has been employed for airport navigation. As of 1992, individuals were utilizing it for home purposes.

Previous studies in Nepal found that solar radiation levels range from 5.33 to 2.08 kWh/square meter/day. According to previous study, Gandaki Provence has the highest potential for solar and wind energy at the subnational level, whereas Karnali province has the most installation capacity in Nepal .Geographical factors such as weather, day length, latitude, longitude, solar zenith angle, and declination can impact solar energy received by solar cells.



Source: SolarGIS

Figure 2: Map showing total Global Horizontal Irradiation(GHI) of Nepal

2.1.3 Electricity Scenarios of Nepal

Modern energy, which includes electricity, petroleum, and renewables, accounts for around 20% of Nepal's overall energy usage, a proportion that is continuously increasing. Among these contemporary energy sources, gasoline accounts for around 65%, followed by electricity (15%) and other sources such as coal (20%). Nepal's need for energy is increasing, particularly in rural places with restricted access. While numerous renewable energy sources are accessible for lighting and cooking, achieving SDG 7—ensuring universal access to affordable, reliable, and modern energy—remains challenging. Nepal pledged to attain net-zero emissions by 2045 during COP26.

2.1.3 Renewable energy policy of Nepal

In the Paris Agreement, countries agreed to limit temperature increases to 1.5 °C. This would result in lower greenhouse gas emissions. Nepal's government committed to reducing greenhouse gas emissions and implemented policies in line with these accords. GON is also working in this sector. As a result, the Nepalese government implemented a policy to capture green energy. The Nepalese government has legal provisions to encourage alternative energy. According to Nepal's constitution. The Nepalese government plans to deploy a mixed energy strategy to provide enough and sustainable energy supply, generate renewable energy, and meet citizens' fundamental requirements.

Nepal's 2015 constitution established local governments. This law outlines particular duty for executing renewable energy initiatives. The local government has the jurisdiction to provide licenses and finance development initiatives. The program allows individuals to sell their alternative energy at a cost of 7.30 per unit for the development of grid-connected alternative energy in 2018.

Nepal's government provided subsidies for solar energy. Money subsidies encourage consumers to build household solar PV systems. The subsidies cover around 40% of the overall installation cost. Nepal's government is working on a joint venture scheme with other donor organizations. The subsidy amount varies depending on the area's remoteness. The same approach is used in the solar street road lighting in urban, rural and remote regions, as well as solar photovoltaic-PV systems in residences, educational institutions/schools, healthcare areas, and religious organizations. The program prioritizes off grid implications, including subsidies for miniand micro hydropowers, advanced water-mills, solar power (home system, mini-grids, grid-connected system), biogases and biomass energy sector , wind power, and also wind-sun hybrids. The policy record includes specific subsidy details for each generation type.

2.2 Photovoltaic energy

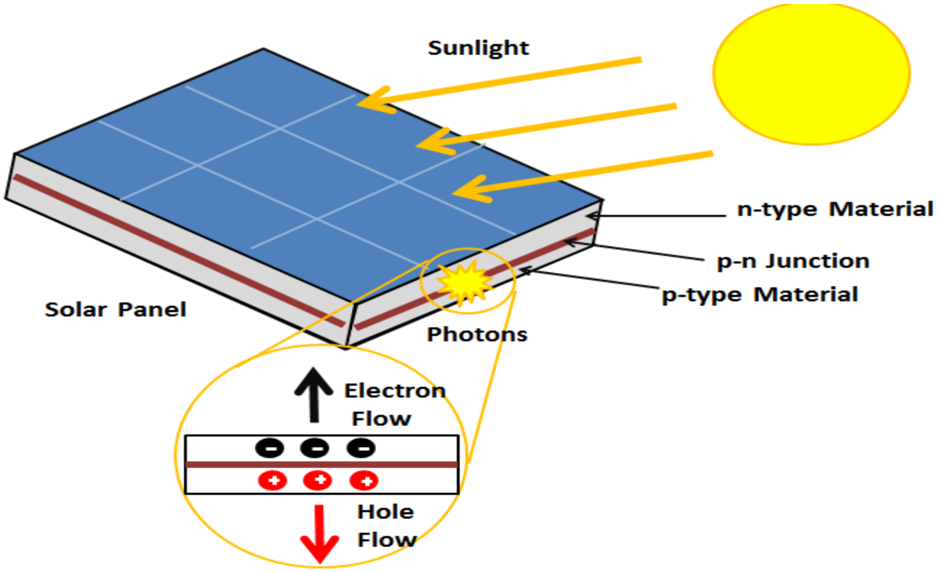
Solar photovoltaic is now one of the most extensively used solar electricity technology in this universe. Solar cells run at ambient temperatures, have no any moving mechanical parts, and can generate at any scales.

A solar Pv-array is made up of one or more linked PV modules and each with a large number of individual solar cells, as well as balance of the system (BOS) hardware components such Joiner boxes, inverter, transformer, rackings, cabling, and enclosure. In a grid connected electrical system, combiner, inverter, and transformer convert the lowvoltage direct (DC) current of several individual PV modules and adding all and producea high voltage AC current electricity that is sent into the grid connection system.

2.3 Photovoltaic (PV) Fundamentals

2.3.1 Photovoltaic Effects

The photovoltaic effect is the mechanism by which some materials produce electricity when exposed to light. In photovoltaic (PV) cells, photons (light particles) impact the semiconductor material, causing electrons to be excited and released from their atoms, resulting in electron-hole pairs. These electrons go through an external circuit and generate power. This process is the foundation of solar cells, which convert sunlight directly into electrical energy. The efficiency of photovoltaic cells is determined by factors such as semiconductor material, sunlight intensity, and solar cell structural design, all of which have an impact on their capacity to successfully capture solar energy.



Source :Energy Education

Figure 3: Photovoltaic(PV) Effect

2.3.2 Photovoltaic terminologies

In this section/part, some of the major Photovoltaic(PV) parameters used in solar manufacturers in the world are described and briefly discussed. This phrase could be ubiquitous in the worldwide PV industry, hence it will be utilized significantly on the thesis work.

Efficiency of the Solar cell (η)

The efficiency (η) of a solar cell is the percentage of sunlight converted into electrical energy. It is governed by the cell's semiconductor material's capacity to convert photons into electricity, as well as the losses suffered during the process. Efficiency is influenced by several factors, including the kind of semiconductor material used, cell design, manufacturing quality, and ambient circumstances like as sunlight intensity and temperature. Higher efficiency cells create more power per unit area of sunlight, making them more cost-effective and attractive for solar energy applications ranging from residential rooftops to large-scale solar farms that want to optimize energy production while reducing space and installation costs.

Fill factor (FF)

The fill factor (FF) assesses how efficiently a solar cell operates. It quantifies the ratio of the maximum power point (MPP) to the product of the short circuit current (Isc) and the open circuit voltage (Voc).

2.3.3 Photovoltaic Solar Cell Type

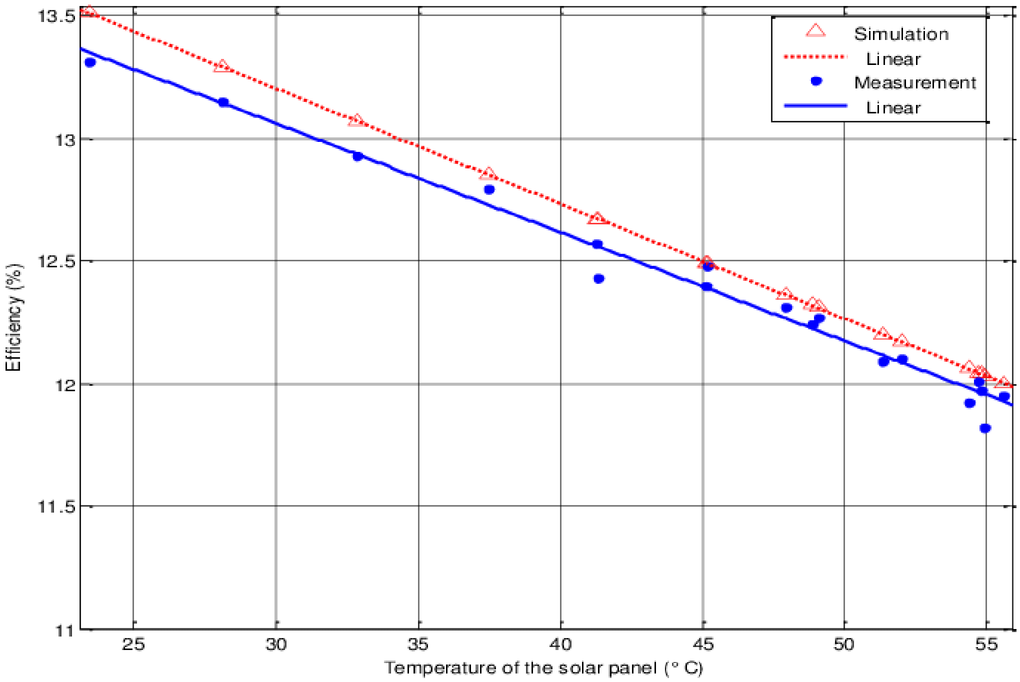
Photovoltaic cells, often known as PV cells, can be made in a number of techniques and materials. Despite their differences, they all accomplish the same task: gathering solar energy and transforming it into usable power. The most often used material for solar panel fabrication is silicon, which possesses semiconducting characteristics.[2] A solar panel requires several of these solar cells, and a photovoltaic array consists of numerous panels. To optimize more efficiencies and capture more energy from the sun, we must choose a best of following cells:

- Monocrystalline
- Polycrystalline
- Thin Film Solar Cells

2.2.4 PV Cell Performance

An I-V curve can also be used to visualize the exact performance of a Photovoltaic(PV) cell as seen in fig.4. The curve indicates the MPP that the cell achieves under specified conditions. Standard testing conditions (STC) and normal operating conditions (NOCT) often give specified circumstances. STC is defined as 1000 W per m2 irradiance at a 25°C ambient temperature with 1.5 air mass(Am) (Guedez 2017). NOCT conditions are employed to better reflect real-world circumstances. In this scenario, we assume an irradiation of 800 W /m2, an ambient air temperature of 20°C, and an average air speed of 1m/s. These two given criteria can be utilized to compute the actual performance of the Photovoltaic cell.

The product of maximum current (Impp) and maximum voltage (Vmpp) represents a PV cell's maximum power output under specific conditions. To determine the maximum power point (Mpp) at any time, PV modules must be used with an Mpp tracker system. Maximum Power Point Trackers (MPPTs) help regulate and optimize the module's operating voltage (V) to maximize the module's current (I).



Source: Researchgate

Figure 4: solar module efficiency(η) with temperature effects

2.2 Impact of Solar Cell Temperature

Temperature changes can have an impact on solar panel efficiency, with greater temperatures frequently resulting in poorer performance due to increased resistive losses and lower output (Joshi et al., 2020).

However, the link between temperature and solar panel efficiency is complicated, as various types of solar panels may have varying temperature coefficients (Skoplaki & Palyvos, 2009).

Temperature(T), open circuit voltage(V_0c) and short circuit current(I_{sc}) were measured during a 10 day time period. The study found that floating solar PV(FSPV) systems provide 11-12% more electricity than land-based systems. Floating solar PV systems absorbed over 1.5% more irradiation than land-based systems (Sah et al.,2021).

Thermal conditions effect both energy generation and PV module efficiency. The given research reveals that under true weather circumstances in Poland, instantaneous power during the summer - when energy output is maximum - can be as much as 21% lower in comparison to nominal PV conditions, resulting in monthly energy production up to 10% lower(Hassan et al. 2016).

2.3 Impact of Humidity and Collective Impact with all parameters

Humidity levels and weather patterns, such as cloud cover and precipitation, can also have an influence on solar panel performance since they alter sunlight availability and atmospheric conditions (Chowdhury et al., 2019).

Cloud cover, in particular, can cause changes in solar irradiance levels, affecting energy output (Möller et al., 2019).

The study examined how relative humidity (RH) affects certain characteristics of an amorphous PV module at Gaston Berger University. The analysis of internal and extrinsic data enabled the evaluation and visualization of efficiency variations. In operating circumstances with an STC value of 4.9%, efficiency was less than 2.3% at RH=51% and decreased to 1.15% with RH close to 86%. More data over a longer period is needed to determine long-term impacts, quantify impact proportions, and characterize the behavior of amorphous PV modules in real-world Saharan circumstances (Soaphys et al. 2019)

.

Collective Impact of solar radiation, cell temperature and humidity

The study found a substantial non-linear association between relative humidity and solar radiation ($R^2 = 0.858$), with an inverse relationship in the morning and a direct relationship in the afternoon. Solar radiation has an average exponential connection with photovoltaic panel efficiency ($R^2 = 0.6317$) and a significant direct linear association with maximum power ($R^2 = 0.955$). The temperature of a PV panel directly correlates with the percentage of efficiency loss, increasing by 0.4695% for each temperature increase over 25°C (Rashid et al., 2021)

Overall, the literature emphasizes the complex interactions between solar panel performance and climatic conditions, emphasizing the significance of thorough investigation in understanding and utilizing solar energy effectively.

CHAPTER 3: METHODOLOGY

Methodology is a method for properly dealing with project details in order to complete a well-balanced project. The conceptual framework for the project is provided below:

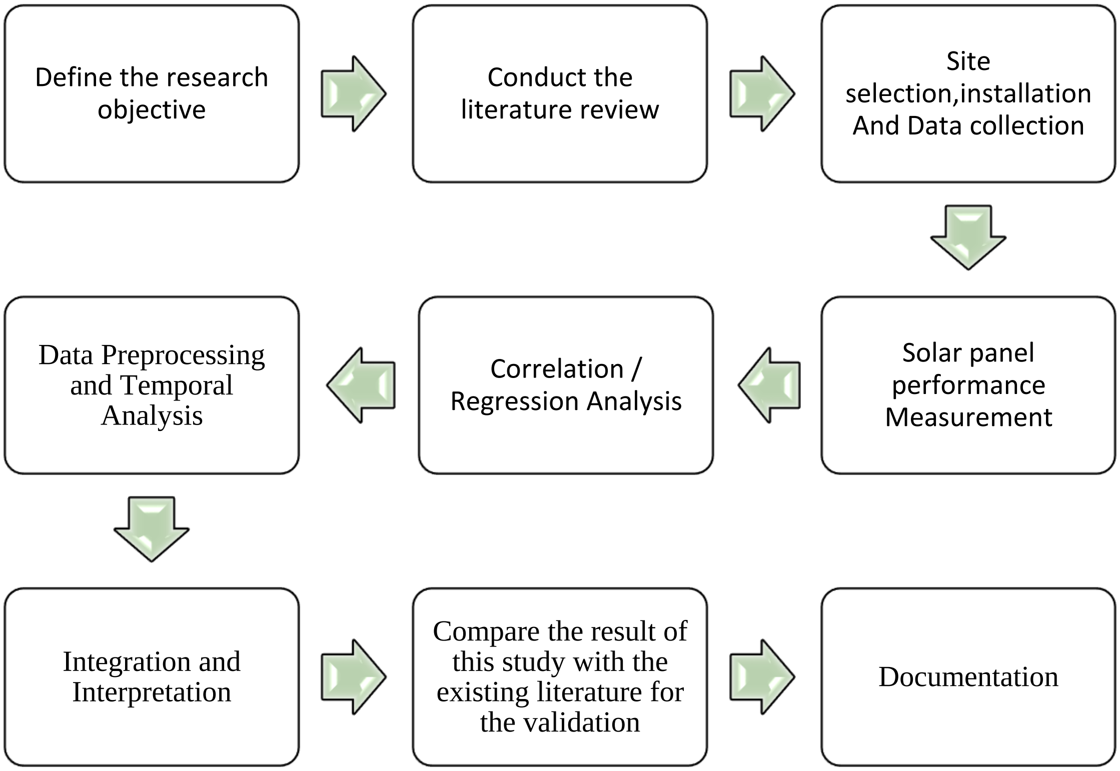


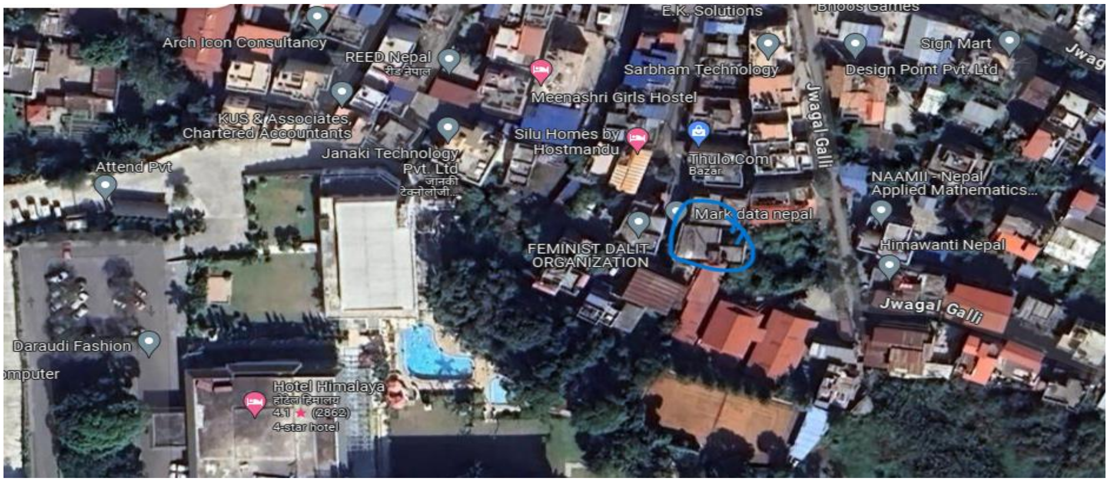
Figure 5:Flowchart for the procedure to conduct the thesis

3.1 Literature review

The foremost step in project management(PM) is to do a literature review. In this part, the effects of different meteorological variables on solar PV system performances were examined. For the literature review, relevant journals, research papers, and textbooks were examined at each stage, and the process will continue throughout the project. According to the literature, numerous climatic conditions affect the effectiveness of a solar photovoltaic system, including sun irradiation, temperature, humidity, and so on.

3.2 Site Selection , Installation And Data Collection

A office building near, Jwagal in Lalitpur is taken as a site for the experiment and solar Panel was installed and data were taken here.



Source: Google Maps

Figure 6:Location showing experiment Site

Table 1:Specification of Solar panel

Production Company Name	Dongguan Sunworth Solar Energy Co. Ltd,China
Panel Model number	SW080P
Serial Number	812190100138
Production time/date	18-01-2019
Peak power(P_{max})	80W
Power tolerance range in	±3W
Open circuit voltage - V_{oC}	21.8V
Rated voltage -V_{mp}	18.1 V
Short circuit current -Isc	4.81 A
Rated current (I_{mp})	4.42 A
Maximum module voltage	600V
Dimension of array in (mm)	895*660*30 mm
Weight in (kg)	6.6 KG
Series fuse rating (A)	10 A
Application class	A

Source : Dongguan Sunworth Solar Energy Co. Ltd,China website

3.3 Solar Panel Performance Measurement

Solar panels were installed in the aforementioned location, together with the necessary equipment for evaluating performance characteristics such as voltage, current, and power generation.

3.4 Correlation Analysis

Excel is used for the Statistical analysis to identify correlations between meteorological parameters and solar panel performance.

3.5 Data Processing and Temporal Analysis

After gathering preliminary data, the temporal fluctuations in climatic factors and solar panel performance were examined to detect patterns and trends over various time intervals.

3.6 Integration and Interpretation

The results of correlation analysis and graphs were combined to acquire a thorough grasp of the links between climatic conditions and solar panel performance.

3.7 Compare the result of this study with the existing literature for the validation

We compared our findings to the current literature and considered the practical implications for solar energy systems.

3.8 Documentation

Finally, documentation of the thesis accomplished.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Data measured

30° was set as a fixed tilt angle for the research and datas were taken from 11th to 17th of march the different parameter measured are tabulated as below.

Table 2:Data measure on 11th March 2024

11-Mar-24							
Time	radition (Watt/m2)	Humidity (%)	Cell Temperature (°C)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	500	32	36	20.47	2.85	58.3395	19.75%
12:00	700	26	43	20.73	3.56	73.7988	17.85%
1:00	700	21	45	20.83	3.64	75.8212	18.34%
2:00	580	18	41	21.06	3.21	67.6026	19.73%
3:00	460	20	34	21.07	2.63	55.4141	20.39%
4:00	280	21	30	20.79	1.54	32.0166	19.36%

Above table shows experimental data of the different solar panel parameters with metereological parameters on 11th March 2024.

Table 3:Data measured on 12th March 2024

12-Mar-24							
Time	radition (Watt/m2)	Humidity (%)	Cell Temperature (°C)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	600	30	33	20.35	3.02	61.457	17.34%
12:00	800	28	38	20.57	3.81	78.3717	16.58%
1:00	800	26	36	20.74	3.95	81.923	17.34%
2:00	600	21	38	20.56	3.11	63.9416	18.04%
3:00	480	21	35	20.4	2.33	47.532	16.76%
4:00	300	23	34	19.49	1.8	35.082	19.80%

Above table shows experimental data of the different solar panel parameters with meteorological parameters on 12th March 2024.

Table 4:Data measured on 13th March 2024

13-Mar-24							
Time	radition (Watt/m2)	Humidity (%)	Cell Temperature (°C)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	640	22	40	20.48	4.12	84.3776	22.32%
12:00	840	19	41	20.62	4.26	87.8412	17.70%
1:00	860	16	47	20.39	4.24	86.4536	17.02%
2:00	760	15	41	20.73	3.89	80.6397	17.96%
3:00	480	16	34	20.64	2.92	60.2688	21.26%
4:00	280	18	28	20.8	1.52	31.616	19.12%

Above table shows experimental data of the different solar panel parameters with metereological parameters on 13th March 2024.

Table 5:Data measured on 14th March 2024

14-Mar-24							
Time	radition (Watt/m2)	Humidity (%)	Cell Temperature (°C)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	800	24	40	20.44	3.95	80.738	17.09%
12:00	860	22	42	20.49	4.01	82.1649	16.17%
1:00	760	18	45	20.75	3.79	78.6425	17.52%
2:00	700	16	39	20.9	3.32	69.388	16.78%
3:00	360	14	30	20.92	2.58	53.9736	25.38%
4:00	300	16	29	21.01	1.85	38.8685	21.93%

Above table shows experimental data of the different solar panel parameters with metereological parameters on 14th March 2024.

Table 6::Data measured on 15th March 2024

15-Mar-24							
Time	radition (Watt/m2)	Humidity (%)	Cell Temperature (°C)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	920	22	38	20.34	4.32	87.8688	16.17%
12:00	920	18	40	20.41	4.37	89.1917	16.41%
1:00	940	17	42	20.6	4.29	88.374	15.92%
2:00	720	13	41	20.65	3.37	69.5905	16.36%
3:00	320	13	37	20.72	2.18	45.1696	23.90%
4:00	240	14	34	20.55	1.6	32.88	23.19%

Above table shows experimental data of the different solar panel parameters with metereological parameters on 15th March 2024.

Table 7:Data measured on 16th March 2024

16-Mar-24							
Time	radition (Watt/m2)	Humidity (%)	Cell Temperature (°C)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	960	24	37	20.34	3.98	80.9532	14.28%
12:00	980	21	39	20.5	4.05	83.025	14.34%
1:00	980	17	40	20.6	4.14	85.284	14.73%
2:00	420	18	33	20.72	3.08	63.8176	25.72%
3:00	300	15	31	20.72	1.79	37.0888	20.93%
4:00	260	15	30	20.68	1.64	33.9152	22.08%

Above table shows experimental data of the different solar panel parameters with metereological parameters on 16th March 2024.

Table 8:Data measured on 17th March 2024

17-Mar-24							
Time	Radition (Watt/m2)	Humidity (%)	Cell Temperature (ºC)	Voltage (V)	Current (A)	Power (Watt)	Efficiency (%)
11:00	960	23	42	20.56	3.95	81.212	14.32%
12:00	980	16	43	20.63	4.02	82.9326	14.33%
1:00	940	14	42	20.72	4.21	87.2312	15.71%
2:00	700	13	38	20.83	3.87	80.6121	19.50%
3:00	300	13	33	20.67	1.91	39.4797	22.28%
4:00	240	14	30	20.58	1.62	33.3396	23.52%

Above table shows experimental data of the different solar panel parameters with metereological parameters on 17th March 2024.

4.2 Correlation and Data Interpretation

4.2.1 Graphs and their pattern

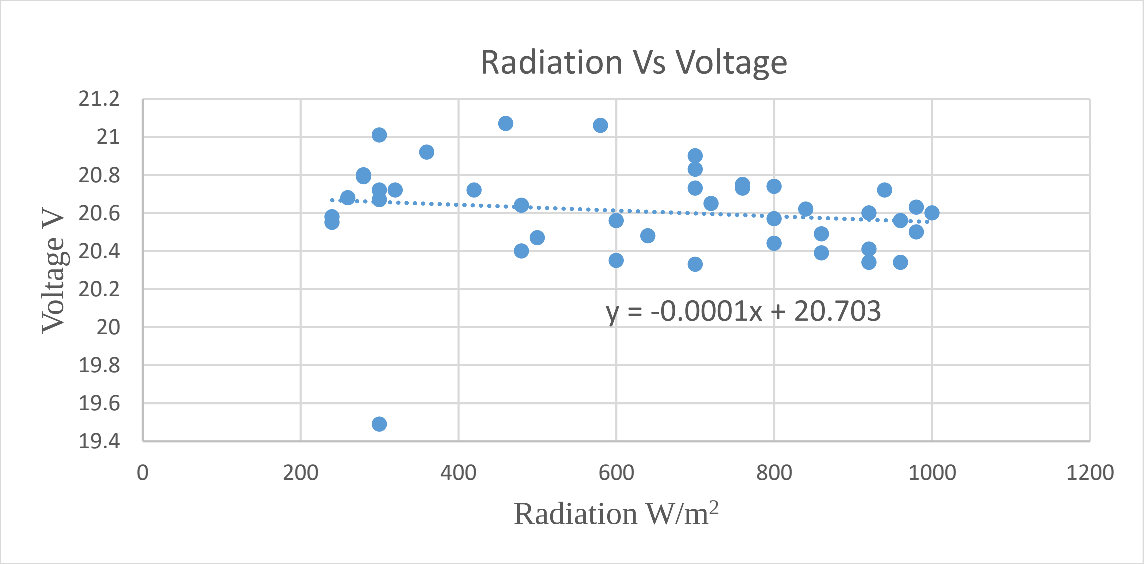


Figure 7:Graphs showing Radiation vs voltage

Figure 7 represents the graphs between voltage and solar radiation,which clearly shows that the voltage and radiation best fit cure has negative slope with positive intercept .from graph we says that voltage slightly decreases when radiation increases.

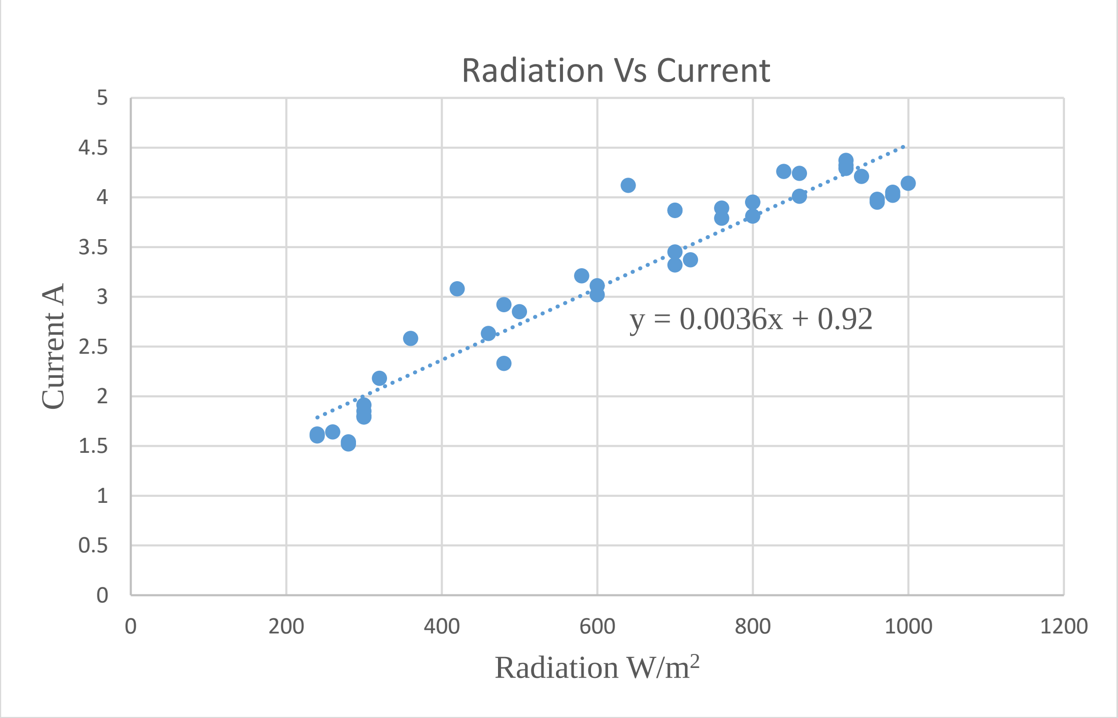


Figure 8:Graphs showing Radiation vs Current

Figure 8 represents the graphs between current and solar radiation,which clearly shows that the current and radiation best fit cure has positive slope with positive intercept .From graph we says that current linearly increases when radiation increases.

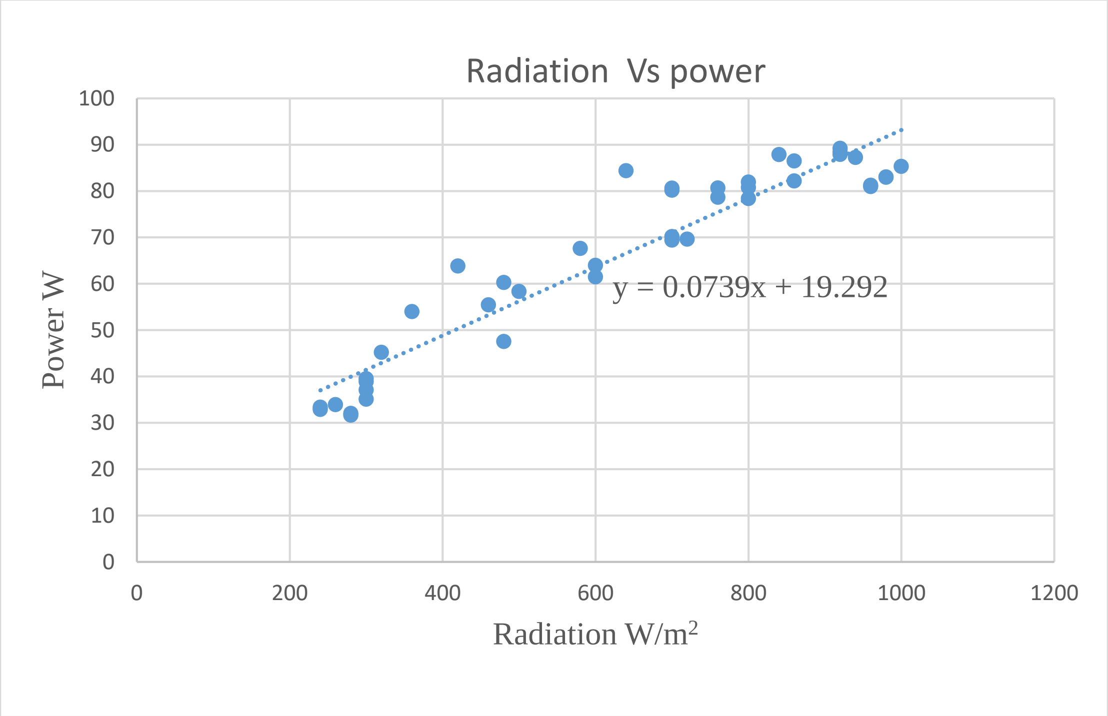


Figure 9:Graphs showing Radiation vs Power

Figure 9 represents the graphs between power and solar radiation,which clearly shows that the power and radiation best fit cure has positive slope with positive intercept .from graph we says that power increases when radiation increases.

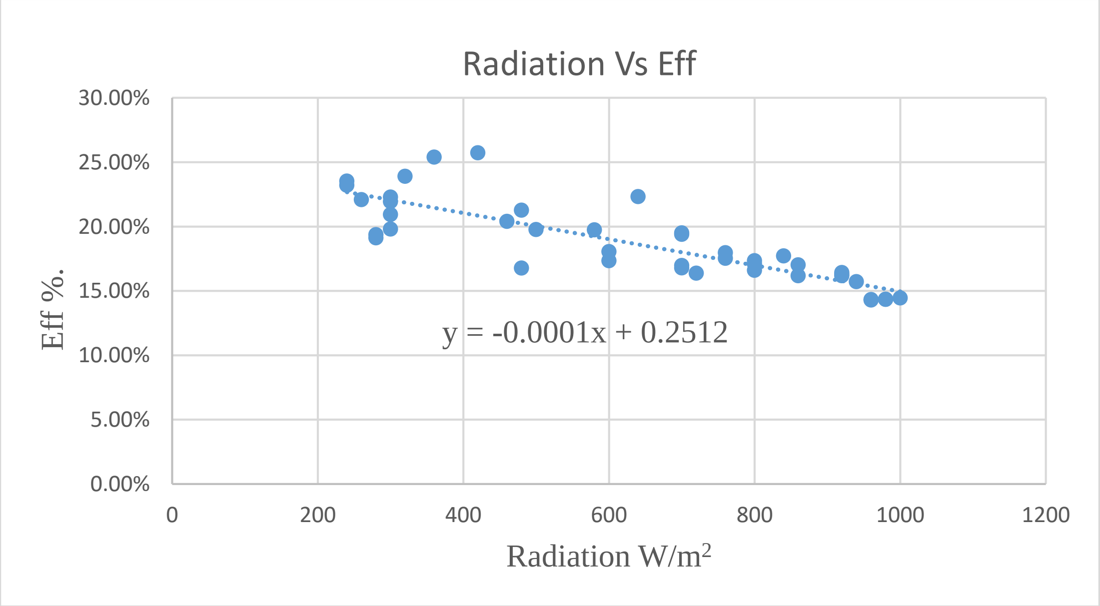


Figure 10:Graphs showing Radiation vs efficiency

Figure 10 represents the graphs between efficiency and solar radiation, which clearly shows that the efficiency and radiation best fit cure has negative slope with positive intercept .from graph we says that efficiency decreases when radiation increases.

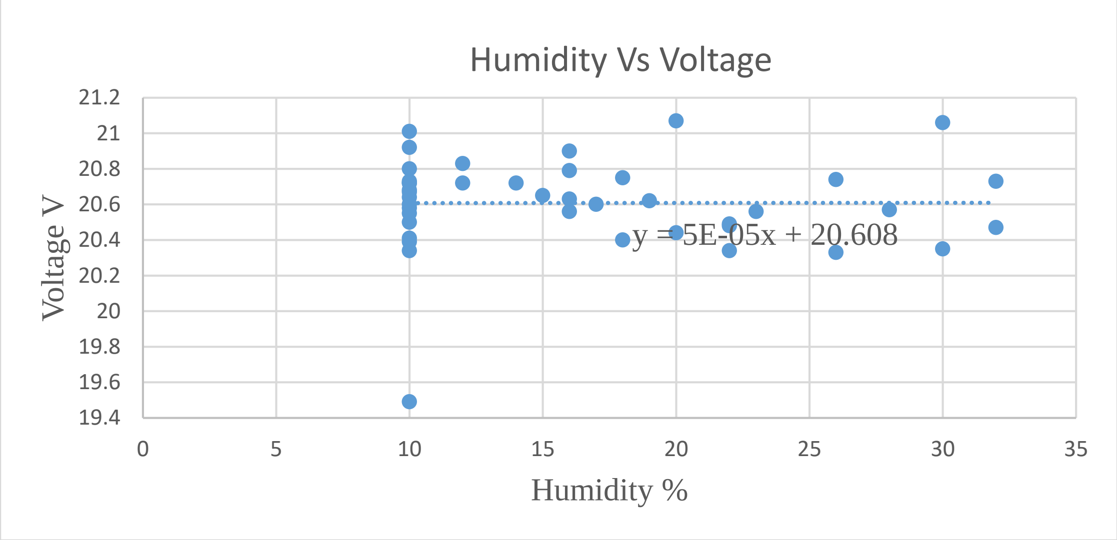


Figure 11:Graphs showing Humidity vs Voltage

Figure 11 represents the graphs between voltage and humidity, which clearly shows that the voltage and humidity best fit cure has positive intercept . From graph we says that voltage and humidity has almost constant relationship.

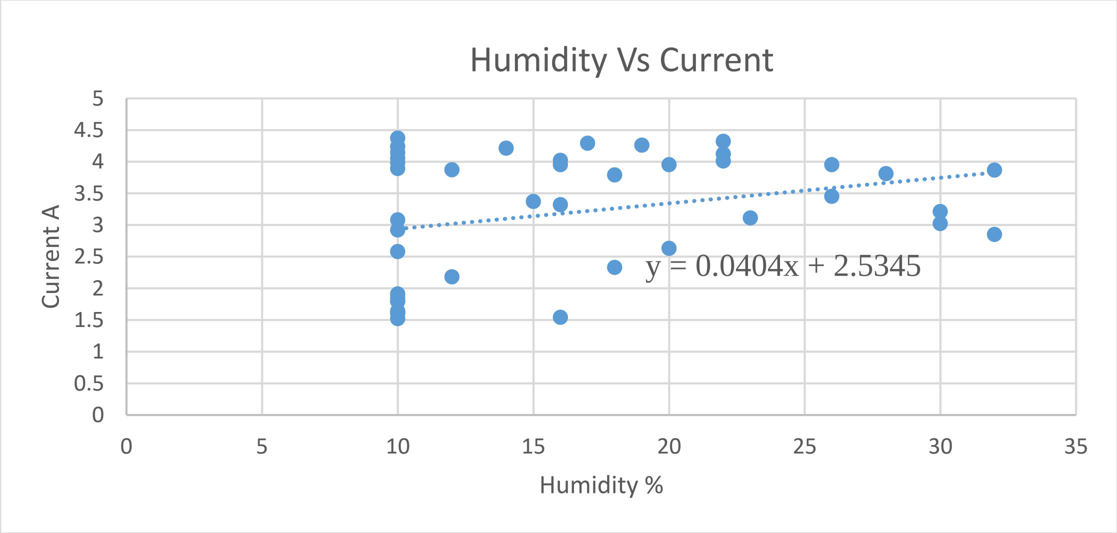


Figure 12:Graphs showing Humidity vs Current

Figure 12 represents the graphs between current and humidity, which clearly shows that thecurrent and humidity best fit cure has positive slope with positive intercept .From graph we can say that current and and humidity has linear relationship.

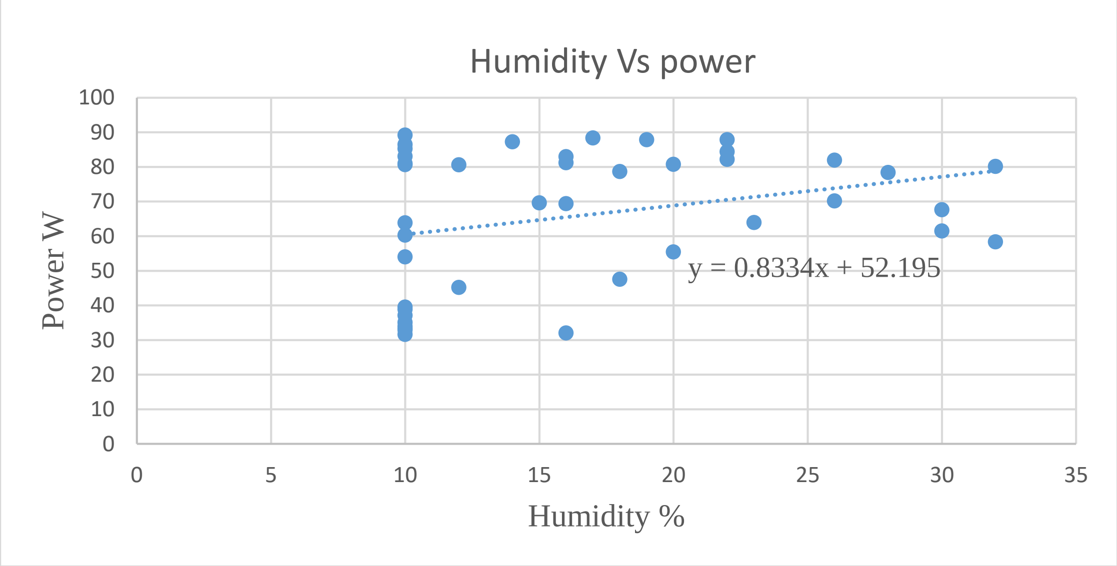


Figure 13::Graphs showing Humidity vs Power

Figure 13 represents the graphs between power and humidity, which clearly shows that the power t and humidity best fit cure has positive slope with positive intercept .From graph we can say that power and and humidity has linear relationship.

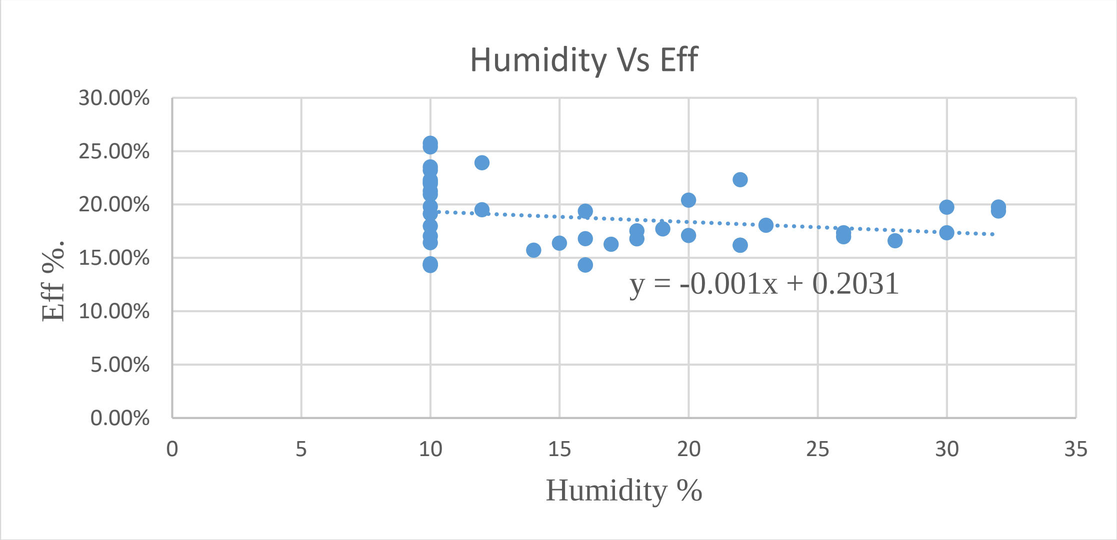


Figure 14:Graphs showing Humidity vs efficiency

Figure 14 represents the graphs between efficiency and humidity, which clearly shows that the efficiency and humidity best fit cure has negative slope with positive intercept .From graph we can say that efficiency and humidity has reciprocal linear relationship.

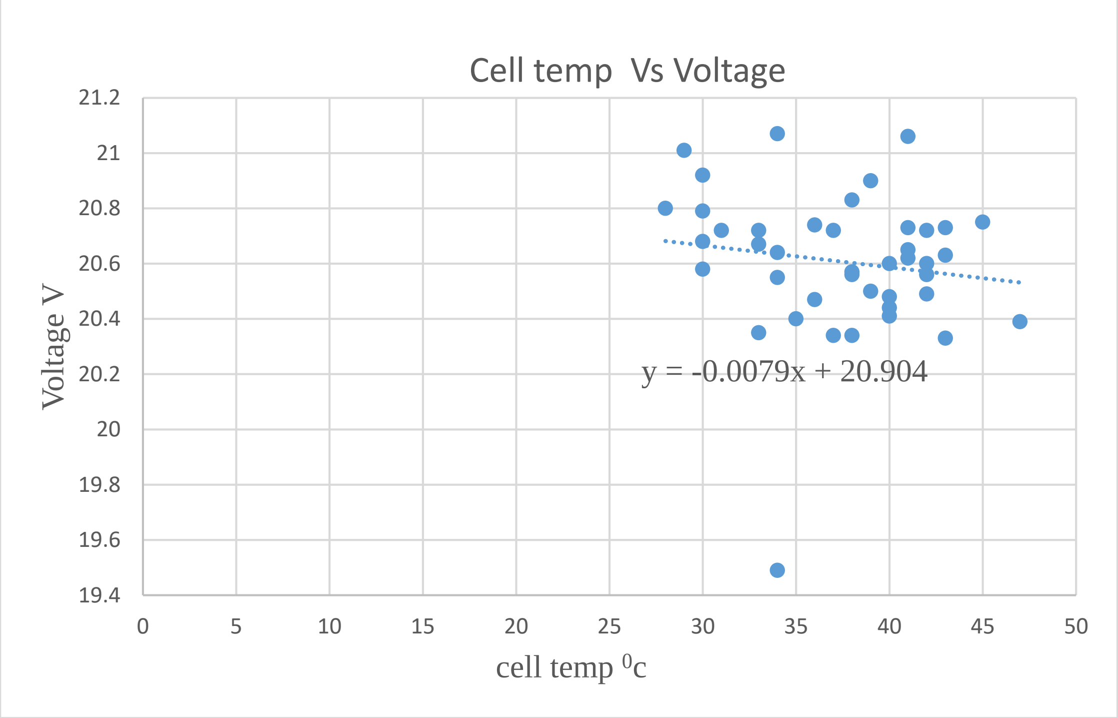


Figure 15:Graphs showing Cell temperarture vs Voltage

Figure 15 represents the graphs between Voltage and cell temperature, which clearly shows that the voltage and cell temperature best fit cure has negative slope with positive intercept .From graph we can say that cell temperature and voltage has reciprocal linear relationship.

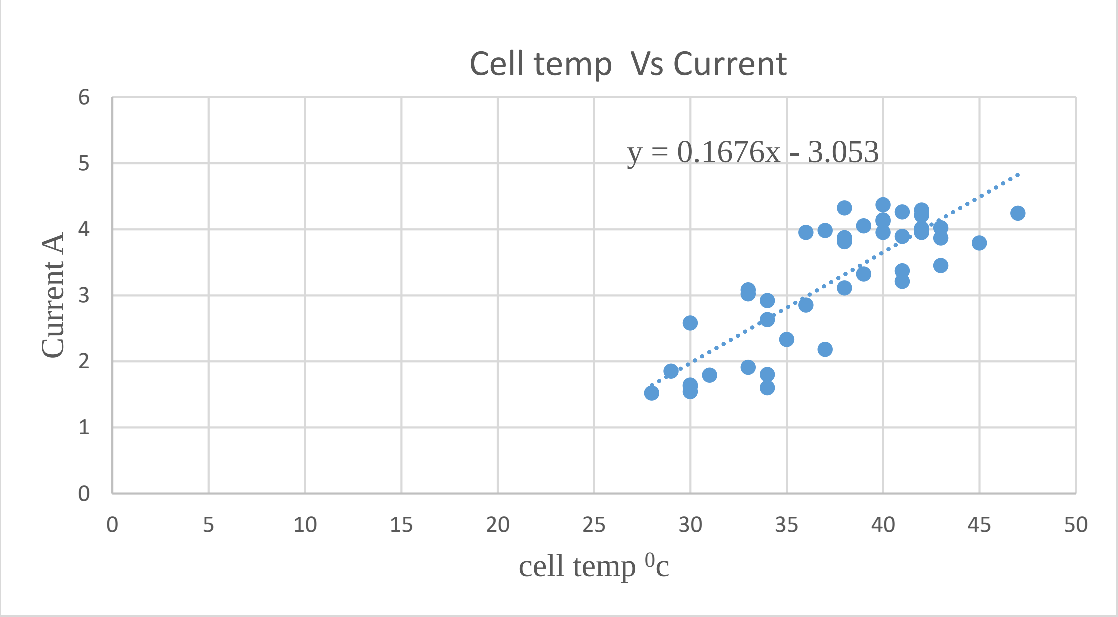


Figure 16:Graphs showing Cell temperarture vs Current

Figure 16 represents the graphs between current and cell temperature, which clearly shows that the current and cell temperature best fit cure has positive slope with negative intercept .From graph we can say that cell temperature and current has linear relationship.

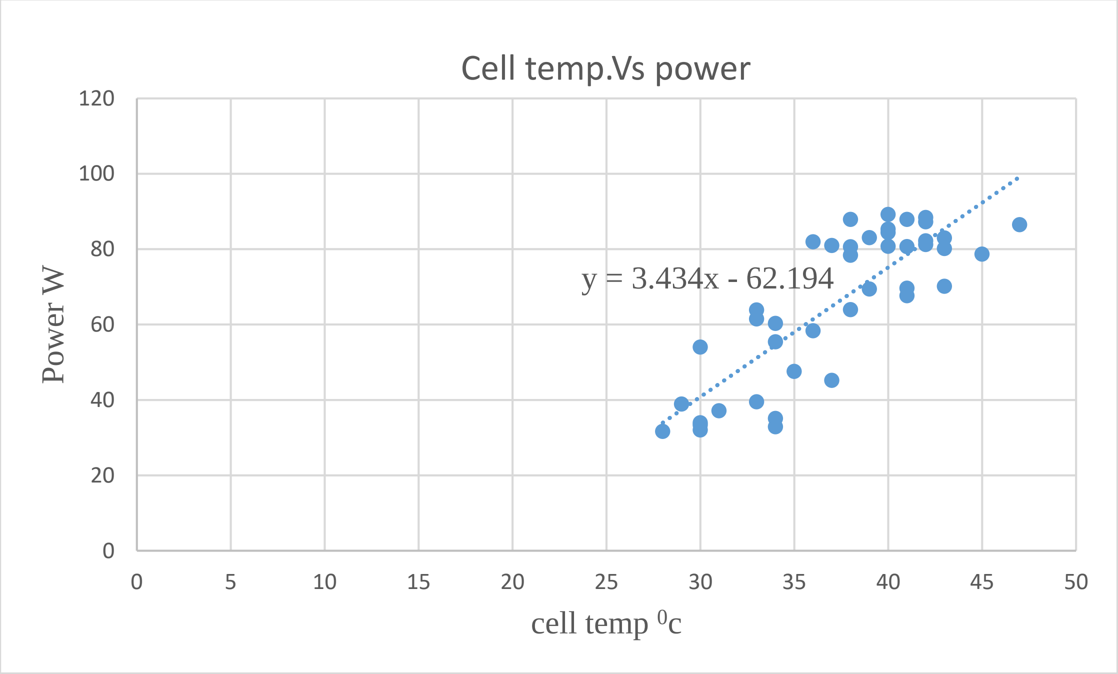


Figure 17::Graphs showing Cell temperarture vs Power

Figure 17 represents the graphs between power and cell temperature, which clearly shows that the power and cell temperature best fit cure has positive slope with negative intercept .From graph we can say that cell temperature and power has reciprocal linear relationship.

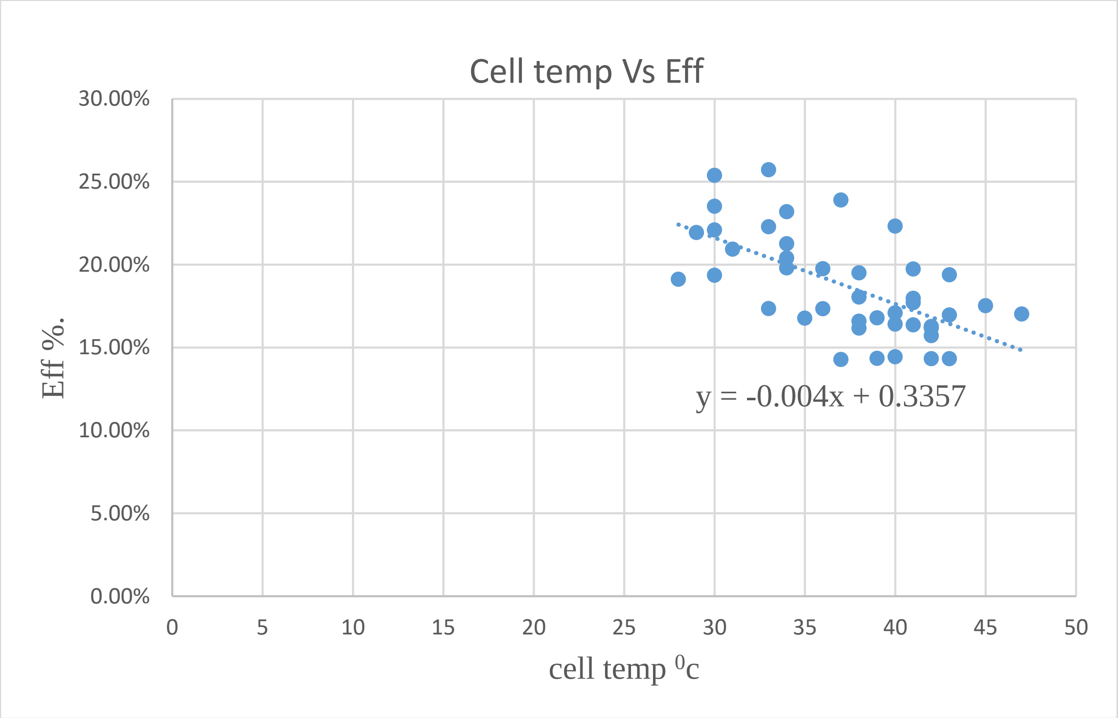


Figure 18:Graphs showing Cell temperarture vs efficiency

Figure 18 represents the graphs between efficiency and cell temperature, which clearly shows that the efficiency and cell temperature best fit cure has negative slope with positive intercept .From graph we can say that cell temperature and humidity has reciprocal linear relationship.

4.2.2 Correlation and regression trend line model

Table 9 Radiation,Humidity and cell temperature and other variables with R and R^2

Correlation Table							
	Radiation	*Humidity*	*Cell Temperature*	*Voltage*	*Current*	*Power*	*Efficiency*
Radiation	1.000000						
Humidity	0.226154	1.000000					
Cell Temperature	0.805137	0.313710	1.000000				
Voltage	-0.146992	0.001355	-0.146189	1.000000			
Current	0.951157	0.297720	0.830429	-0.095138	1.000000		
Power	0.948213	0.299346	0.829359	-0.062935	0.999416	1.000000	
Efficiency	-0.839034	-0.225032	-0.619129	0.267240	-0.661679	-0.653798	1.000000

	Voltage	*Current*	*Power*	*Efficiency*
Determination of coefficient of R^2 (Radiation with Voltage,current,power and efficiency	0.022	0.905	0.899	0.704
Determination of coefficient of R^2 (Humidity with Voltage,current,power and efficiency	0.000	0.089	0.090	0.051
Determination of coefficient of R^2 (Humidity with Voltage,current,power and efficiency	0.690	0.688	0.383	0.383

Linear Regression trendline model predicted from the above experimented data using excel are as follows:

(x: Radiation and y: voltage)

y= -0.00014 * x + 20.70290 ………………………………………eq^n 1

(x: Radiation and y: current)
y = 0.00361* x + 0.91996 ………………………………………eq^n 2

(x: Radiation and y: power)

$y= 0.07385* x + 19.29216$ ……………………………………eq^{n} 3

(x: Radiation and y: efficiency)

$y= -0.00010 * x + 0.25116$ ……………………………………eq^{n} 4

Linear Regression trendline model predicted from the above experimented data using excel are as follows:

(x: Humidity and y: voltage)

$y = 4.93361E-05 * x + 20.60752$ …………………………………eq^{n} 5

(x: Humidity and y: current)

$y = 0.04040 * x + 2.53445$ ……………………………………eq^{n} 6

(x: Humidity and y: power)

$y = 0.83341 * x + 52.19467$ …………………………………… eq^{n} 7

(x: Humidity and y: efficiency)

$y = -0.00097 * x + 0.20305$ ……………………………………eq^{n} 8

Linear Regression trendline model predicted from the above experimented data using excel are as follows:

(x: cell temperature and y: voltage)

$y= -0.00792 * x + 20.90375$ …………………………………… eq^{n} 9

(x: cell temperature and y: current)
$y = 0.16760* x -3.0530$ …………………………………………eq^{n} 10

(x: cell temperature and y: power)

$y=3.43398 * x - 62.19402$ ……………………………………eq^{n} 11

(x: cell temperature and y: efficiency)

$y = -0.00399 * x + 0.33571$ ……………………………………eq^{n} 12

4.3 Discussion

From experiment ,if we analyzing data between 11 PM to 4 PM , Relative humidity tends to decreases up to 3 PM and then begins to increases gradually. Also experiment reveals cell temperature tends to increase up to 1 PM and then tends to decrease.

From graph of radiation vs current, voltage,power and efficiency, it reveals that the voltage and efficiency decreases if radiation increases but the power and current be increased when radiation increases. And also from the graph between humidity and other parameters like current, voltage ,power and efficiency, we can see that the voltage is almost constant, current and powwr increases but the efficiency gets decreased when humidity increases due to the deposition of water droplets on the surface of the solar panel.from the graph between cell temperature vs other parameters we can reveal that voltage and efficiency decreases but current and power increases when cell temperature increases. Among all the graphs ,we also could revel that the efficiency will be decreases when the metereological parameters like radiation, humidity and cell temperature increases.

From the correlation table we could reveal that coefficient achieved a value of 0.022, 0.905, 0.899, 0.704 for the R^2 (for Radiation with voltage, Current, power and efficiency respectively) which shows strong relationship with current, power and efficiency and less correlation with voltage. coefficient achieved a value of 0.000,0.089,0.090 ,0.051 for the R2 (for Humidity with voltage, Current, power and efficiency respectively) which shows strong relationship with current,and power and mid relationship with efficiency and very less almost zero correlation with voltage. coefficient achieved a value of 0.690 ,0.688, 0.383, 0.383for the R2 (for Cell temperature with voltage, Current, power and efficiency respectively) which shows strong relationship with voltage and current less relationship with efficiency and power .

Regression trendline model illustrates how radiation affects efficiency. Equation indicates that an increase in radiation has an adverse influence on the panel's efficiency. Further support for this conclusion (-0.00010) comes from equation y= -0.00010 * x + 0.25116 which has a negative coefficient. According to this, the solar panel's efficiency decreases by 0.00010 for each watt per square metre that the radiation rises. This is consistent with earlier research findings.

Regression trendline model illustrates how radiation affects efficiency. Equation indicates that an increase in humidity has an adverse influence on the panel's efficiency. Further support for this conclusion (-0.00097) comes from equation y = -0.00097 * x + 0.20305 which has a negative coefficient. According to this, the solar panel's efficiency decreases by 0.00097 for each percentage that the humidity rises. This is consistent with earlier research findings.

Regression trendline model illustrates how radiation affects efficiency. Equation indicates that an increase in cell temperature has an adverse influence on the panel's efficiency. Further support for this conclusion (-0.00399) comes from equation y = -0.00399 * x + 0.33571 which has a negative coefficient. According to this, the solar panel's efficiency decreases by 0.00399 for each degree celcious that the cell temperature rises. This is consistent with earlier research findings.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Solar panel efficiency are generally improved when decreasing the solar pv cell temperature , humidity and solar radiation .Panel's efficiency decreases by 0.00010 for each watt per square metre that the radiation rises, efficiency decreases by 0.00097 for each percentage that the humidity rises and efficiency decreases by 0.00399 for each degree Celsius that the cell temperature rises.
2. From the data table and discussion, we can conclude that solar radiation has most significant impact on solar PV efficiency (R^2 =0.704) then cell temperature (R^2 =0.383) and less with humidity (R^2 =0.051) .
3. For better optimization of Solar PV performance, deposition of water droplets in PV panel should be decreases and shouldn't exceed maximum operating temperature and radiation limit of solar panel.
4. This experiment improves understanding of the link between solar panel performance and climatic conditions, providing significant information for increasing solar energy systems' efficiency and dependability in various environment conditions.

5.2 Recommendations

1) Installing solar trackers that follow the sun's movement throughout the day maximizes exposure to sunlight and Place reflecting objects, such as mirrors or white materials, surrounding the panels to enhance the quantity of sunlight that reaches them.
2) Solar cells should be properly encapsulated to prevent them from moisture and humidity, which can damage performance. Clean the panels on a regular basis to eliminate dirt, dust, and other debris, which can collect and limit efficiency, particularly in humid situations.
3) Use active cooling devices like liquid cooling or fans to lower the temperature of solar cells, especially in hot conditions and if we use materials with excellent thermal conductivity to effectively disperse heat and avoid temperature buildup in cells could increase solar efficiency

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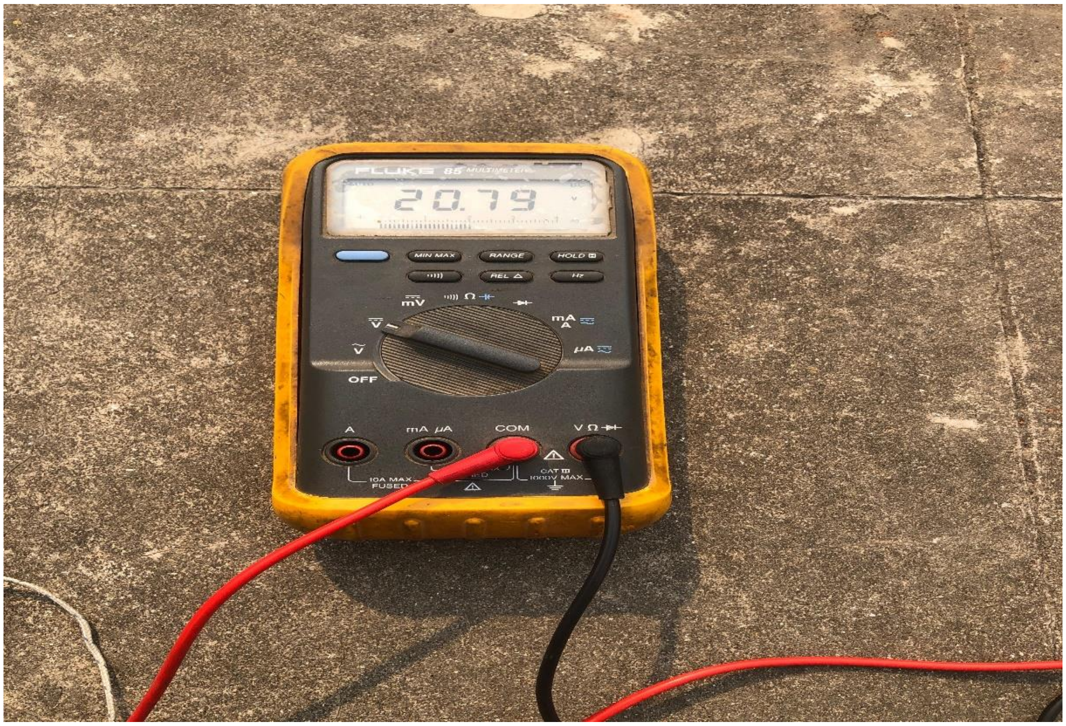
ANNEXES

	Area of panel		0.5907	m^2	Solar Panel angle 30^0				
		11 March 2024 to 17 March 2024							
S.N		Time	Radiation	Humidity	Cell Temperature	Voltage	Current	Power	Efficiency
1	11-Mar	11::00 AM	500	32	36	20.47	2.85	58.3395	19.75%
2		12::00 PM	700	32	43	20.73	3.866	80.14218	19.38%
3		1::00 PM	700	26	43	20.33	3.45	70.1385	16.96%
4		2:00: PM	580	30	41	21.06	3.21	67.6026	19.73%
5		3:00: PM	460	20	34	21.07	2.63	55.4141	20.39%
6		4:00: PM	280	16	30	20.79	1.54	32.0166	19.36%
7	12-Mar	11::00 AM	600	30	33	20.35	3.02	61.457	17.34%
8		12::00 PM	800	28	38	20.57	3.81	78.3717	16.58%
9		1::00 PM	800	26	36	20.74	3.95	81.923	17.34%
10		2:00: PM	600	23	38	20.56	3.11	63.9416	18.04%
11		3:00: PM	480	18	35	20.4	2.33	47.532	16.76%
12		4:00: PM	300	10	34	19.49	1.8	35.082	19.80%
13	13-Mar	11::00 AM	640	22	40	20.48	4.12	84.3776	22.32%
14		12::00 PM	840	19	41	20.62	4.26	87.8412	17.70%
15		1::00 PM	860	10	47	20.39	4.24	86.4536	17.02%
16		2:00: PM	760	10	41	20.73	3.89	80.6397	17.96%
17		3:00: PM	480	10	34	20.64	2.92	60.2688	21.26%
18		4:00: PM	280	10	28	20.8	1.52	31.616	19.12%
19	14-Mar	11::00 AM	800	20	40	20.44	3.95	80.738	17.09%
20		12::00 PM	860	22	42	20.49	4.01	82.1649	16.17%
21		1::00 PM	760	18	45	20.75	3.79	78.6425	17.52%
22		2:00: PM	700	16	39	20.9	3.32	69.388	16.78%
23		3:00: PM	360	10	30	20.92	2.58	53.9736	25.38%
24		4:00: PM	300	10	29	21.01	1.85	38.8685	21.93%
25	15-Mar	11::00 AM	920	22	38	20.34	4.32	87.8688	16.17%
26		12::00 PM	920	10	40	20.41	4.37	89.1917	16.41%
27		1::00 PM	920	17	42	20.6	4.29	88.374	16.26%
28		2:00: PM	720	15	41	20.65	3.37	69.5905	16.36%
29		3:00: PM	320	12	37	20.72	2.18	45.1696	23.90%
30		4:00: PM	240	10	34	20.55	1.6	32.88	23.19%
31	16-Mar	11::00 AM	960	10	37	20.34	3.98	80.9532	14.28%
32		12::00 PM	980	10	39	20.5	4.05	83.025	14.34%
33		1::00 PM	1000	10	40	20.6	4.14	85.284	14.44%
34		2:00: PM	420	10	33	20.72	3.08	63.8176	25.72%
35		3:00: PM	300	10	31	20.72	1.79	37.0888	20.93%
36		4:00: PM	260	10	30	20.68	1.64	33.9152	22.08%
37	17-Mar	11::00 AM	960	16	42	20.56	3.95	81.212	14.32%
38		12::00 PM	980	16	43	20.63	4.02	82.9326	14.33%
39		1::00 PM	940	14	42	20.72	4.21	87.2312	15.71%
40		2:00: PM	700	12	38	20.83	3.87	80.6121	19.50%
41		3:00: PM	300	10	33	20.67	1.91	39.4797	22.28%
42		4:00: PM	240	10	30	20.58	1.62	33.3396	23.52%

Photographs 1:Clampmeter and Oryx thermoCouple for Temperature Measurement

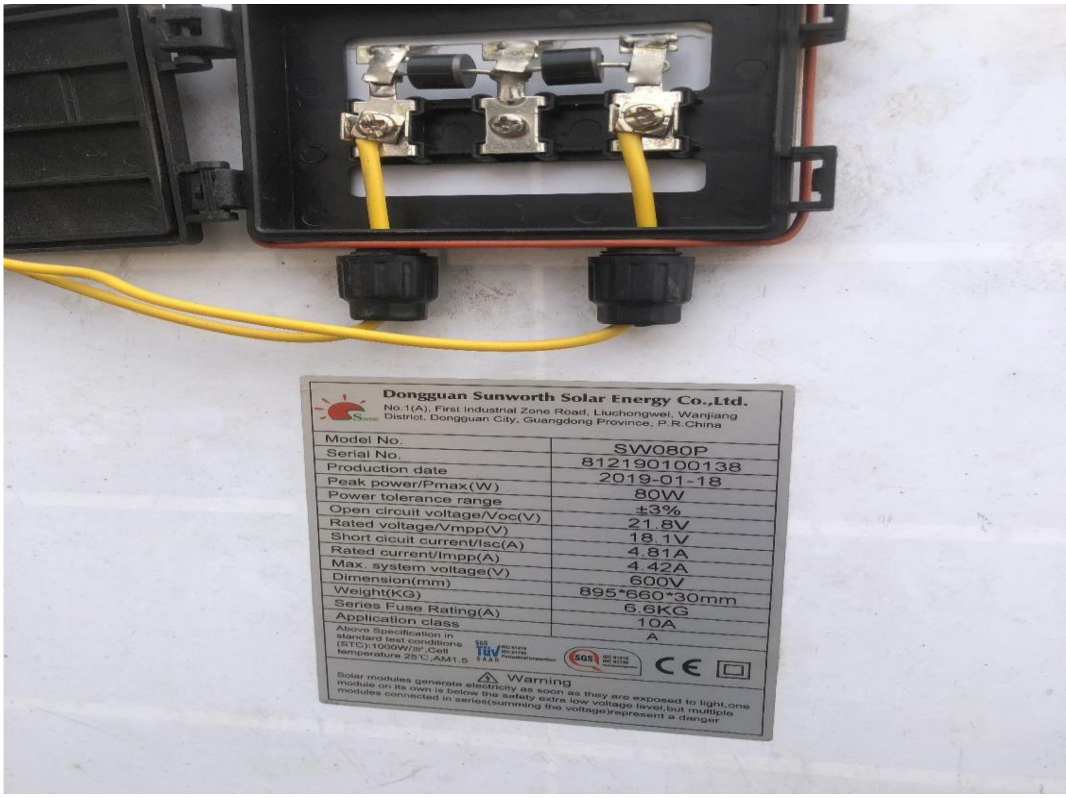


Photographs 2: Fluke Multimeter for measuring Current and Voltage

Photographs 3 : Digital Thermo hygrometer for measuring humidity

Photographs 4 : Overall setup (i)

Photographs 5 : Overall setup (ii)



Dongguan Sunworth Solar Energy Co.,Ltd.
No.1(A), First Industrial Zone Road, Liuchongwei, Wanjiang
District, Dongguan City, Guangdong Province, P.R.China

Model No.	SW080P
Serial No.	812190100138
Production date	2019-01-18
Peak power/Pmax(W)	80W
Power tolerance range	±3%
Open circuit voltage/Voc(V)	21.8V
Rated voltage/Vmpp(V)	18.1V
Short cicuit current/Isc(A)	4.81A
Rated current/Impp(A)	4.42A
Max. system voltage(V)	600V
Dimension(mm)	895*660*30mm
Weight(KG)	6.6KG
Series Fuse Rating(A)	10A
Application class	A

Above Specification in standard test conditions (STC):1000W/㎡,Cell temperature 25℃,AM1.5

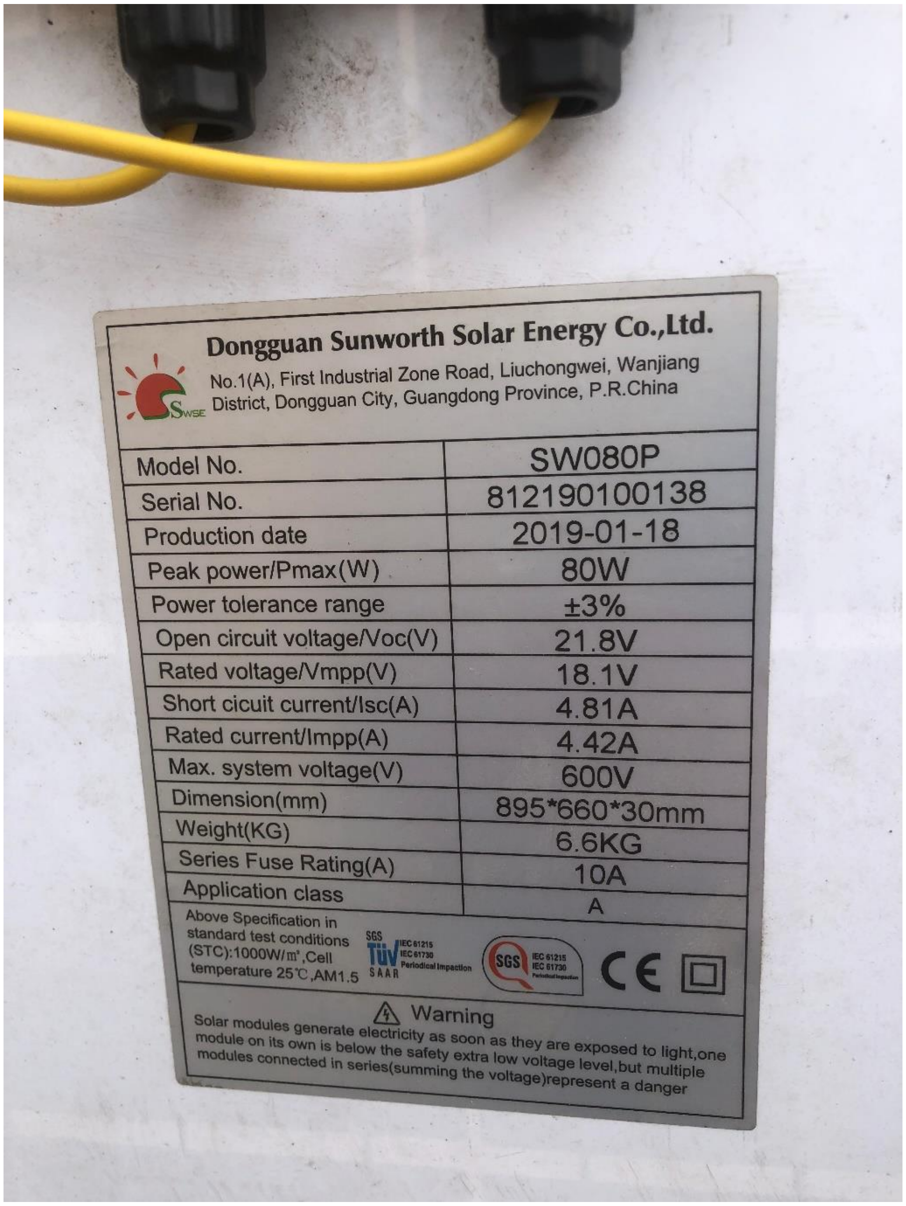
⚠ Warning

Solar modules generate electricity as soon as they are exposed to light,one module on its own is below the safety extra low voltage level,but multiple modules connected in series(summing the voltage)represent a danger

Photographs 6 : Panel Specifications

Photographs 8 cell temperature measurement process

Photographs 9 overall setup with instruments



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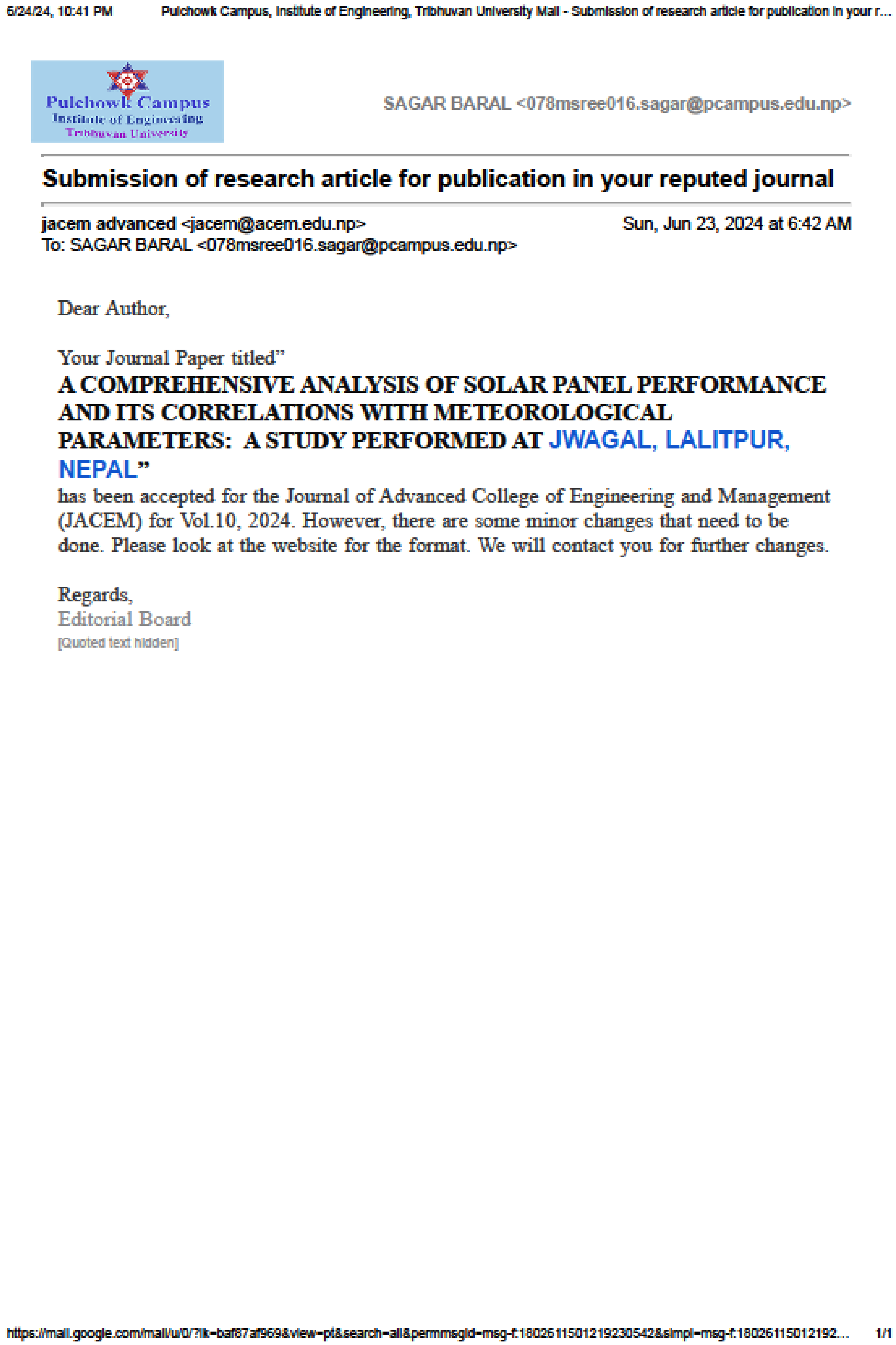
⚠ Warning

Solar modules generate electricity as soon as they are exposed to light,one module on its own is below the safety extra low voltage level,but multiple modules connected in series(summing the voltage)represent a danger

Photographs 10 panel specification (Back side)



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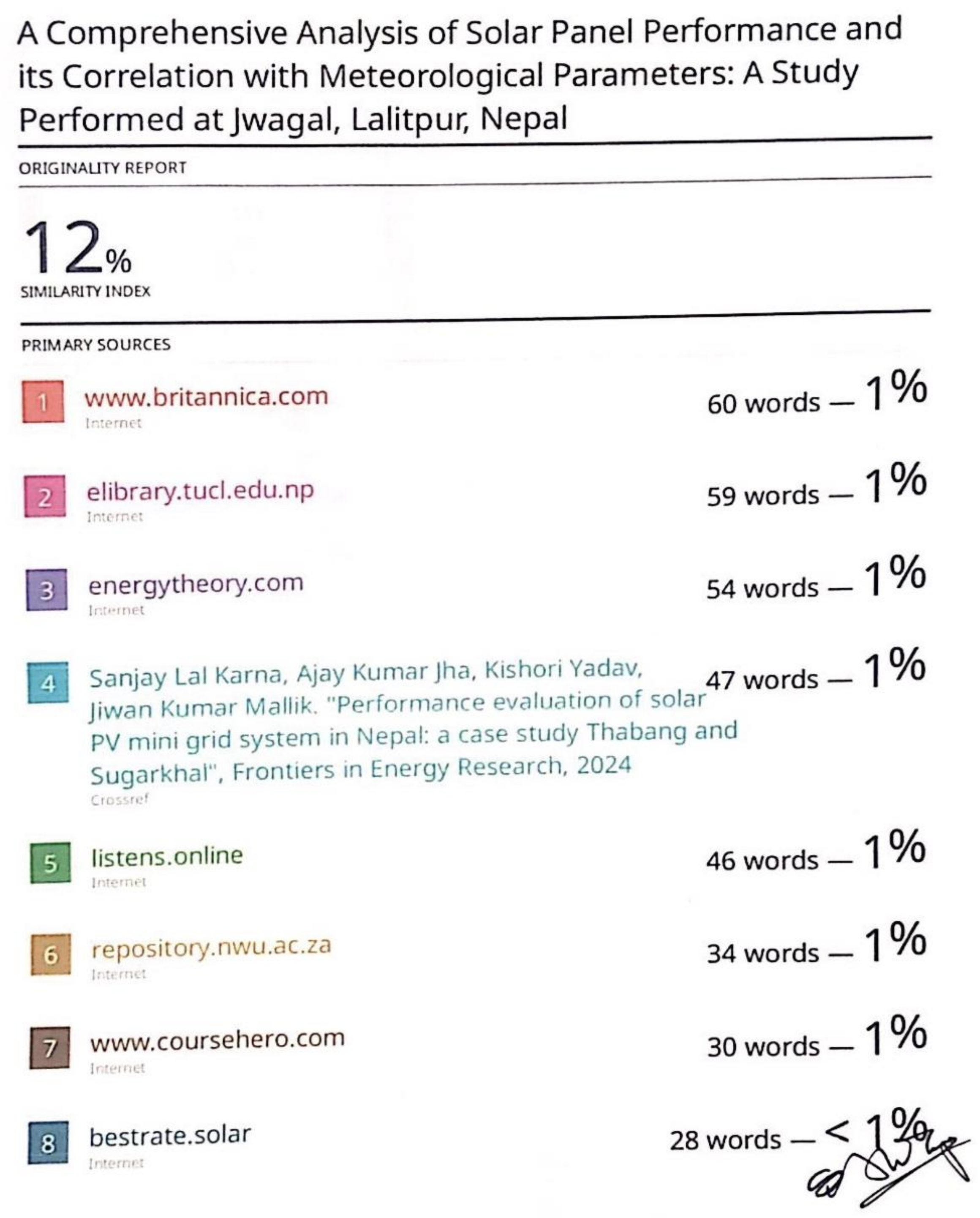

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