BIOMIMICRY IN PV PANELS (OPTIMIZATION OF SOLAR TRACKERS USING WATER FLOW DOUBLE GLAZING TECHNIQUE)

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DEDICATION

I dedicate this thesis to my parents, who have always motivated me and gave me strength.

To my parents:

For their love, for their sacrifices,

And for letting me read a lot when I was a kid.

Chaudhary Ahsan Ali

Enrolment No. 01-244201-002

ACKNOWLEDGEMENT

A thesis report of this breadth and scope could not possibly be assembled by me alone, and so several words of thanks are in order. First, I would like to thank Allah Almighty for bestowing me energy and will that enabled me to compile and produce this report. Next, I would like to thank **Dr. Imtiaz Alam** Bahria University Islamabad**.**

I also thank him as he is my project supervisor who helped me in every difficulty which I faced while completing this project. He always encouraged me in problem solving during the project. It is important to thank the people who've supplied mainly beneficial assistance, technical or otherwise, throughout the thesis.

ABSTRACT

This research addresses the drawbacks of conventional technological arrangements of solar parks and the major causes of failure that occur due to lesser advancements in the arrangements of PV Panels in Solar Plants. The comparison of old and new techniques (idle arrangement to solar tracking PV Panels that can automatically detect the maximum irradiance and can track the Sun light for maximum possible output and enhanced cooling technique such as water flow double glazing technique) are made in this work. The existing system and the proposed system are compared with each other, and the results can considerably increase in the annual plant capacity of the existing system. The proposed technique can help maximizing the overall production of a solar plant. The Quaid-e-Azam solar park was taken as a case study which was initially designed to produce 100MW initially but is only producing 18MW. Certain enhancements that are needed to maximize the plant capacity are proposed under the scope of this research along with design implementation and results. The design aspects of the plant that are linked with the overall production enhancement are the main concern of this research. WFDG (Water Flow Double Glazing) technique is proposed to increase the electrical efficiency of PV Panels by maintaining the temperature of PV Panel to (30-35) ^{o}C. This WFDG technique is implemented in this research to maximize the efficiency of PV Panels in Solar Trackers.

KEYWORDS: Photovoltaic, Solar Tracking, Water Glazing, Cooling Technique.

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LIST OF ABBREVIATIONS

WFDG	Water Flow Double Glazing
PVGIS	Photovoltaic Geographical Information System
PV	Photovoltaic
MW	Mega Watts
CFD	Computational Fluid Dynamics
TRNSYS	Transient Systems Simulation Program

LIST OF SYMBOLS

$\dot{m}$	Water Mass Flow Rate and is Denoted by kg/s
C_p	The Specific Heat Of Water J/kg.K
T_w	The Water Temperature in Chamber
T_{ext}	External Temperature
T_{in}	Internal Temperature
G	Solar Irradiance
A	Window Surface That Is Directed Orthogonally to The Direction of Sun Rays
a_w	Absorption Factor of Water Chamber
τ	Solar Transmittance
h_{ext}	External Heat Transfer Coefficient
h_{int}	Internal Heat Transfer Coefficient

CHAPTER 1

INTRODUCTION

CHAPTER 1

1. INTRODUCTION

1.1. THESIS BACKGROUND/OVERVIEW

Solar System allows to harness the energy from the Sun that can be a source of green and clean energy. The threat of global warming has alarmed many countries to adopt the renewable methods of energy production to survive and enjoy nature in a more sustainable method. Sun is the ultimate source of energy for the Earth. Photo Voltaic Panels are used to convert this useful energy of the Sun rays into electricity. World is moving rapidly to achieve more sustainable sources of energy.

Initially the National Power Project under Quaid-e-Azam Solar Park in Bahawalpur faced major controversy because it was designed to produce an overall power of 100MW but is only producing 18MW. The necessary improvements that are needed to enhance the overall production of the plant are to be proposed in this research. Solar Tracking Combined with Double Glazing Cooling Model for the Design would be proposed and the net increase in the overall yield of the Solar Park will be a major step towards renewable energy advancement in Pakistan. Solar energy being an abundant form of renewable energy is present in the nature and this energy is clean and easily accessible in Pakistan. Solar energy is being consumed naturally to provide heat, light, and electricity. Harmful effects such as pollution and global warming are prevented due to the use of solar energy.

The PV panels receive 80% of solar irradiance that falls on their surface, but a little amount of electrical energy is harnessed from the PV panels out of total irradiance falling on the surface of the panel. The rest of the energy is dissipated as heat, and it causes the overall increase of the temperature of solar panel. It is observed that in case of crystalline silicon PV panels the electrical output is decreased from 0.2-0.5 % for each degree Celsius rise in the temperature of PV module. The maximum power output of the PV panel is reduced when the temperature of the panel rises. There is a need to maintain and monitor the temperature of PV panels to achieve maximum output from the panels.

This research mainly aims toward the cooling technique for the efficient working of solar panels. The rear and the front sides of the solar panel are cooled, and the specially designed chambers are designed to establish a direct contact between water and the surface of panel to enhance solar efficiency. The work helps optimizing the overall renewable energy struggles of Pakistan and maximizing production capacity of the already installed solar parks of Pakistan. The improved model along with comprehensive results would be shared after the successful increase in overall efficiency of the solar plants under consideration.

1.2. PROBLEM DESCRIPTION

The PV panels receive 80% of solar irradiance that falls on their surface, but a little amount of electrical energy is harnessed from the PV panels out of total irradiance falling on the surface of the panel. The rest of the energy is dissipated as heat, and it causes the overall increase of the temperature of solar panel. It is observed that in

case of crystalline silicon PV panels the electrical output is decreased from 0.2-0.5 % for each degree Celsius rise in the temperature of PV module. The maximum power output of the PV panel is reduced when the temperature of the panel rises. There is a need to maintain and monitor the temperature of PV panels to achieve maximum output from the panels.

The performance of a PV module depends on the following factors:

- Incident Solar Radiation
- Wind Speed
- Ambient Temperature
- Geometry of the Collector
- Heat Transfer Fluid

This research mainly aims toward the cooling technique for the efficient working of solar panels. The rear and the front sides of the solar panel are cooled, and the specially designed chambers are designed to establish a direct contact between water and the surface of panel to enhance solar efficiency. The WFDG chamber is proposed for the cooling purpose of PV Panels, and it will contain double panes of clear acrylic plastic sheets. Water will be filled inside these sheets and the whole arrangement will be placed in contact with the PV Panel Surface.

The overall Plant Production Capacity is enhanced using proposed model. The Enhancement in the overall plant capacity would be shown as the physical proof to prove the credibility of this work and its dire need to adopt would be highlighted to maximize the overall production capacity of solar parks and to use the maximum energy from the Sun to convert it into electricity.

1.3. THESIS OBJECTIVES

This thesis has the following objectives:

- Combining the Technique of Glazing with the tracking model to see the improvements in overall production capacities of the system.
- Using front water-cooling chamber executes; PV panel cooling and filtering the Sun's irradiance as well as reducing its sunlight reflection falling on it.
- The average reduction in the PV panel temperature is 45.56 %, 40.12% and 50.06% with using (front, rear, and both sides) cooling chambers respectively.
- With using both sides cooling technique, the PV average electrical power and the electrical efficiency enhanced by 12.69% and 14.204% respectively.
- For every 1 degree Celsius below 25 degree the maximum solar efficiency of the panel increases by 0.38%.
- Observing the positive enhancement in the overall production of Plant with the desired arrangements and proposing these changes to be adopted in future installation of plants.

1.4. THESIS ORGANIZATION

The thesis is organized in the following manner:

- Chapter 1 (This chapter reviews Introduction, Overview, Problem Description, Thesis Objective and Thesis Organization)
- Chapter 2 (Detailed Literature Review is provided in this chapter)
- Chapter 3 (Detailed Methodology is provided in Chapter 3)
- Chapter 4 (Test System and the Results of the Proposed Technique)
- Chapter 5 (Results and Discussions)
- Chapter 6 (Conclusion and Future Work)

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

2. LITERATURE REVIEW

Solar System allows to harness the energy from Sun that can be a source of green and clean energy. The threat of global warming has alarmed many countries to adopt the renewable methods of energy production to survive and enjoy nature in a more sustainable method. Sun is the ultimate source of energy for Earth. Photo Voltaic Panels are used to convert this useful energy of the Sun rays into electricity. World is moving rapidly to achieve more sustainable sources of energy.

The different configurations and the components that are used in the water-based cooling techniques for cooling the PV Panels are reviewed in this section. Leonforte and Aste, del Pro proposed that the medium used for cooling the panels have a higher impact on optimizing the electrical efficiency of solar panel [1]. Water for instance, have a higher heat capacity and for that reason it allows stable temperature control for PV systems. Water that absorbs the heat of PV Panels can then be used for domestic needs in most of the cases. The techniques proposed by different authors include glazing, non-glazing, and semi-transparent chambers for cooling the PV Panels that are partially or fully covered by transparent sheets or containers. Different types of coatings are suggested for this purpose to mathematically analyse the impact of water cooling on PV Panels and their enhanced efficiency which is then simulated in TRNSYS by Aste and his members in their research [2]. The researchers also proposed the uncovered mc-Si PV module that is bonded with an aluminium absorber. A cylindrical storage tank helps in storing the water that is circulated with the help of a circulation pump. The experiment was carried out in Milan, Italy and the results confirmed that the system's thermal efficiency was 15% and the electrical efficiency was 10%.

In New Delhi, experiments were carried out by Shyam in 2016 using a water collector and glazed tubes that partially covered the PV panel and were transparent to allow the sun rays to fall but only to control the temperature of the PV Panels. Different weather conditions were considered in his experimentation and results were computed with the help of simulations that were made in MATLAB.

PV cell coverage factor is explained in research where proposed systems with the coverage factor of 0.4, 0.56 and 0.7 which resulted in the thermal efficiencies of 58, 51 and 64 percent respectively [3].

It was experimentally investigated by different researchers in their research that the front surface cooling with the help of water increases the performance of PV Module. Thermal efficiency and the electrical efficiency of the PV Panel with and without water flow are compared by energy balance equations considering different weather conditions. The results concluded that the improved electrical efficiency by front water cooling is 9-12 percent in summer.

CFD (Computational Fluid Dynamics) simulations are performed for the experimental study of PV systems by Misha in her research for the weather conditions in Malaysia. 100 Litre water tank was used by the researcher and was used for inletting the water in the cooling mechanism that is used for PV Panels optimization. The outlet water is provided to the heat exchanger and the cold water enters in the storage tank; the storage tank then pumps the water into the cooling mechanism of Solar Panel. The maximum electrical efficiency declared by using this technique was 11.71 percent [4].

The heat transfer procedure of the system is affected by the contact area of cooling chamber. The experiments were conducted for PV Panel cooling techniques by various researchers in different weather conditions. The tube cooling methodology is adopted by different researchers for enhancing the heat exchange effect and balancing the system by backplane cooling of the PV module.

Initially the National Power Project under Quaid-e-Azam Solar Park in Bahawalpur faced major controversy because it was designed to produce an overall power of 100MW but is only producing 18MW. Figure 1 shows a bird eye view of 100 MW Solar Power Plant at Bahawalpur that is considered for necessary improvements that are needed to enhance the overall production of the plant in this research.

Figure 1. Quaid-e-Azam Solar Power (Pvt) Ltd

The Solar Tracking Combined with Double Glazing Cooling Model for the Design would be proposed and the net increase in the overall yield of the Solar Park will be a major step towards renewable energy advancement in Pakistan.

Solar energy being an abundant form of renewable energy is present in the nature and this energy is clean and easily accessible in Pakistan. Solar energy is being consumed naturally to provide heat, light, and electricity. Harmful effects such as pollution and global warming are prevented due to the use of solar energy.

The PV panels receive 80% of solar irradiance that falls on their surface, but a little amount of electrical energy is harnessed from the PV panels out of total irradiance falling on the surface of the panel. The rest of the energy is dissipated as heat, and it causes the overall increase of the temperature of solar panel. It is observed that in case of crystalline silicon PV panels the electrical output is decreased from 0.2-0.5 % for each degree Celsius rise in the temperature of PV module. The maximum power output of the PV panel is reduced when the temperature of the panel rises. There is a need to maintain and monitor the temperature of PV panels to achieve maximum output from the panels.

Figure 2 provides a schematic diagram of cooling system that is considered as an initial design for starting this research. Upper and lower cooling chambers are proposed in this diagram as followed in WFDG technique to enhance the electrical output of the PV Panels.

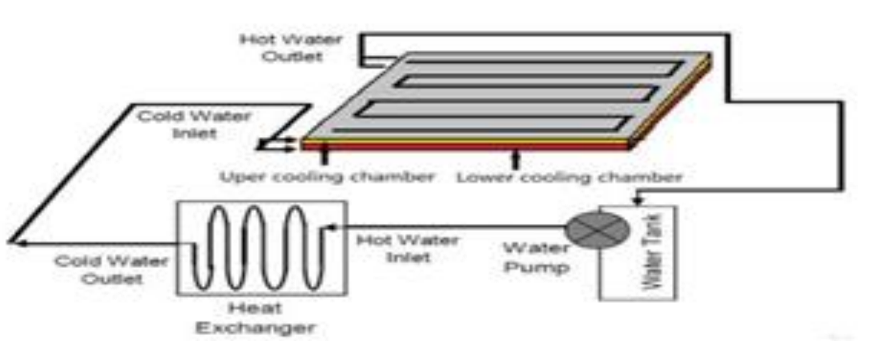


Figure 2. Schematic Diagram of the Cooling System

The performance of a PV module depends on the following factors:

- Incident Solar Radiation
- Wind Speed
- Ambient Temperature
- Geometry of the Collector
- Heat Transfer Fluid

This research mainly aims toward the cooling technique for the efficient working of solar panels. The rear and the front sides of the solar panel are cooled, and the specially designed chambers are designed to establish a direct contact between water and the surface of panel to enhance solar efficiency [5].

The work will contribute to the overall renewable energy struggles of Pakistan and maximizing production capacity of the already installed solar parks of Pakistan.

The improved model along with comprehensive results would be shared after the successful increase in overall efficiency of the solar plants under consideration.

The efficiency of a solar panel is dependent on the radiation, temperature, and wind speed [6]. The material of the panel also played a vital role in the overall efficiency of the PV panel. The Analysis of the QASP power plant model shows that the overall power produced by the plant in first year is 136,700 MWh. The projected power to be produced by the plant in a lifespan of 25 years is 3,108,450 MWh. Although there are certain parameters regarding the Levelized Cost of Energy, but I would be focusing on the generation parameter of the PV plant.

When this project was inaugurated by Mian Muhammad Nawaz Sharif it was generating 50 MW daily. The Government claimed that soon this plant would produce 80 MW of electricity, but after some time the overall energy generation from the plant declined to 18 MW which was a failure of the prediction system. Some researchers are of the opinion that mercury's temperature in the plant should be at 45 degrees for the best efficiency.

The angle at which the Sun rays fall at a PV Panel and the temperature of the PV Panel effects the overall electricity production and efficiency of the solar panels [7].

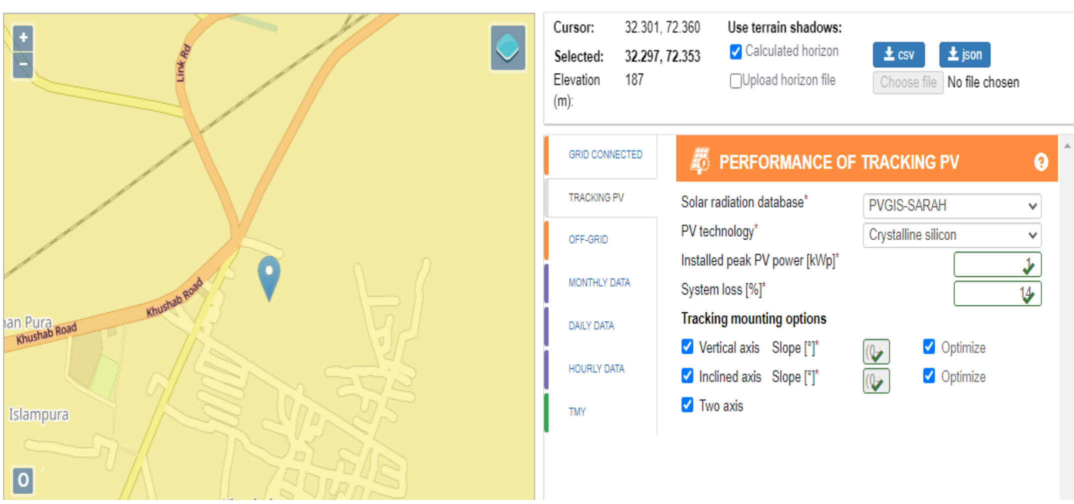


Figure 3. PVGIS Global Map and Performance of Tracking PV

The PVGIS Global Map and Performance of Tracking PV System is calculated and is elaborated in Figure 3. The necessary arrangements to optimize the performance of the Tracking PV System are automatically calculated by the tool considering the geographical position of the plant to be installed.

Location [Lat/Lon]:	32.297 72.353
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Slope angle [Â°]:	50 (opt);33 (opt);
Yearly PV energy production [kWh]:	1933.86;1934.44;1992.58
Yearly in-plane irradiation [kWh/m2]:	2573.94;2574.08;2658.27
Year-to-year variability [kWh]:	32.9;32.9;34.3
Angle of incidence [%]:	-1.74; -1.73; -1.68
Spectral effects [%]:	0.42;0.42;0.42
Temperature and low irradiance [%]:	-11.46; -11.45; -11.72
Total loss [%]:	-24.87; -24.85; -25.04

Table 1 Calculations done by PVGIS

Table 1 shows the design parameters and the calculations done by PVGIS. Slope angle optimization, yearly production, angle of incidence are the important calculations done by PVGIS as shown in Table 1.

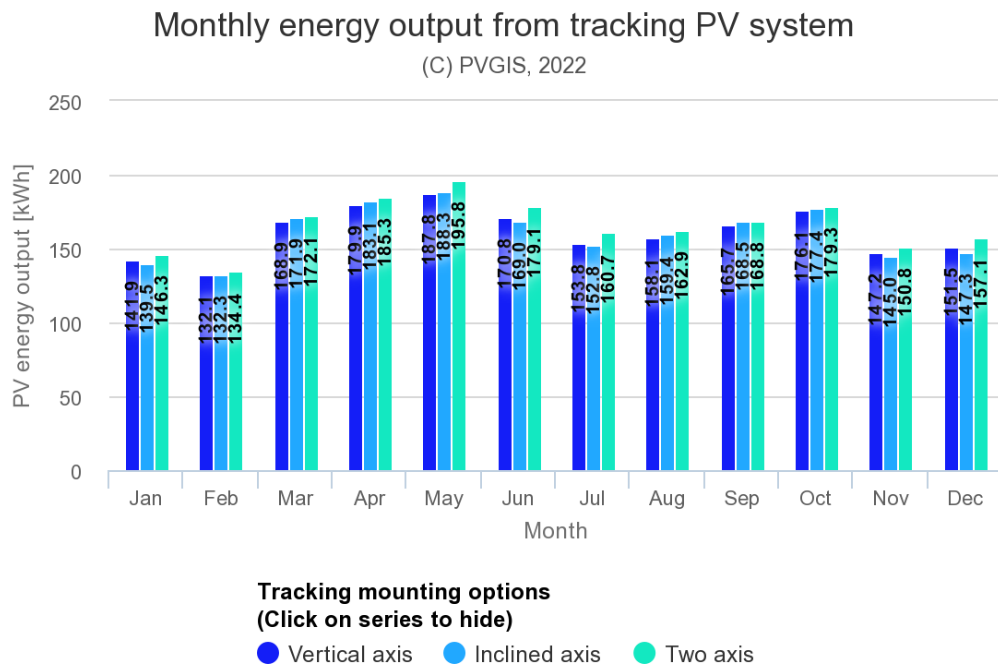


Figure 4. Monthly Energy Output from Tracking PV System

Monthly Energy Output of the Tracking PV System is shown in Figure 4, where vertical axis, inclined axis and two axis arrangement of PV Panels is compared, and the PV Energy Output is compared in bar graph. These are the three mounting options as proposed by PVGIS with their energy output per month.

Figure 5 shows the outline of Horizon as calculated by the geographical location of the plant to be installed. This is proposed by PVGIS and the parameters that are considered in this figure are the Horizon Height, Sun Height June, Sun Height December. This means that this is the type of calculation that helps in forecasting the future height of the Sun in coming months.

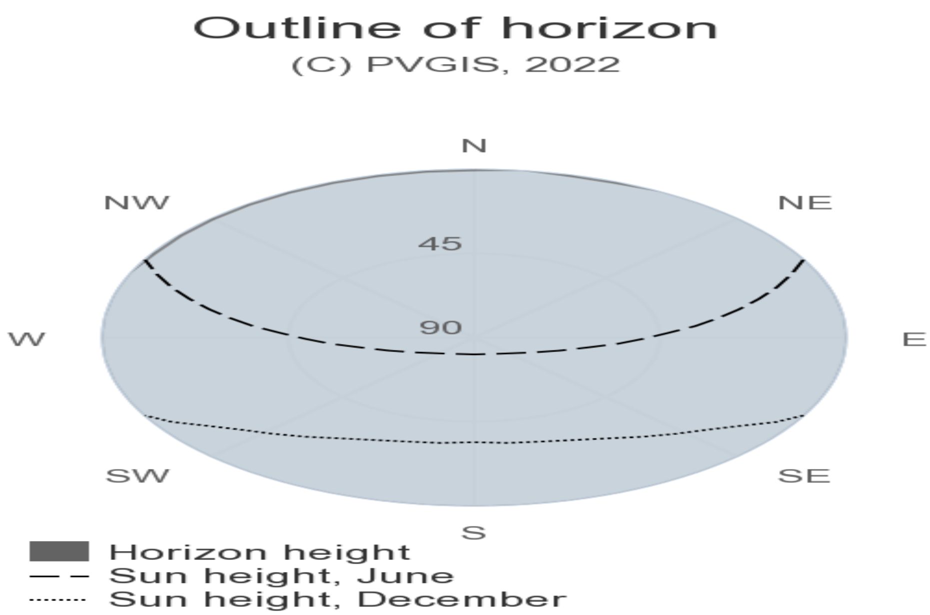


Figure 5. Outline of Horizon by PVGIS

European Commission

Performance of tracking PV

PVGIS-5 estimates of solar electricity generation

Provided inputs:

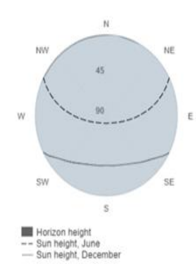
Latitude/Longitude:	32.297, 72.353
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed:	1 kWp
System loss:	14 %

Simulation outputs

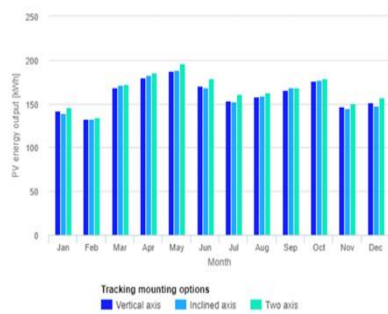
	VA*	IA*	2A*
Slope angle [°]:	50 (opt)	33 (opt)	-
Yearly PV energy production [kWh]:	1933.86	1934.44	1992.58
Yearly in-plane irradiation [kWh/m²]:	2573.94	2574.08	2658.27
Year-to-year variability [kWh]:	32.9	32.9	34.3
Changes in output due to:			
Angle of incidence [%]:	-1.74	-1.73	-1.68
Spectral effects [%]:	0.42	0.42	0.42
Temp. and low irradiance [%]:	-11.46	-11.45	-11.72
Total loss [%]:	-24.87	-24.85	-25.04

* VA: Vertical axis
IA: Inclined axis
2A: Two axis

Outline of horizon at chosen location:



Monthly energy output from tracking PV system:



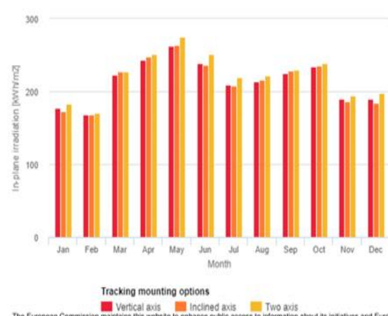
	Vertical axis			Inclined axis			Two axis		
Month	E_m	H(i)_m	SD_m	E_m	H(i)_m	SD_m	E_m	H(i)_m	SD_m
January	141.9	177.0	14.9	139.5	173.2	14.5	146.3	182.5	15.9
February	132.1	167.8	20.2	132.3	167.7	20.2	134.4	170.7	20.8
March	168.9	222.9	18.4	171.9	226.8	18.7	172.1	227.2	18.8
April	179.9	243.2	7.7	183.1	248.0	8.0	185.3	251.1	7.9
May	187.8	263.0	5.6	188.3	264.0	5.7	195.8	275.5	5.8
June	170.8	238.5	6.1	169.0	236.2	6.2	179.1	251.5	6.5
July	153.8	209.3	5.8	152.8	208.4	5.8	160.7	219.8	5.9
August	158.1	213.9	9.0	159.4	216.1	9.1	162.9	221.3	9.2
September	165.7	224.6	9.7	168.4	228.5	10.0	168.8	229.0	9.9
October	176.1	234.0	6.3	177.4	235.4	6.4	179.3	238.2	6.6
November	147.2	189.6	8.9	145.0	185.9	8.8	150.8	194.2	9.5
December	151.5	190.1	11.9	147.3	183.7	11.6	157.1	197.3	12.8

E_m:Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Monthly in-plane irradiation for tracking PV system:



Report generated on 2022/02/24

Figure 6. PVGIS Complete Report File

Figure 6 is the complete Report file of the PV Plant installation as proposed by PVGIS on the desired geographical Location. The location that is considered in this report is Khushab, Pakistan. The latitude and the longitude of the location are 32.297 72.353.

The tracking mechanism supports in minimizing the fall angle problem and the temperature problem of PV is catered by Water Flow Double Glazing Technique. The temperature of panel is reduced this way by using WFDG Technique and it increases the overall electrical efficiency of the panels [8][9]. This certain enhancement is affiliated to increase the overall efficiency of the plant and theoretical results will be drawn via implementation of practical changes in the overall assembly of the plant.

Theory will be combined with the proposal of a practical model to enhance the overall efficiency of the plant [10]. This research will provide the basic grounds for future scholars to apply the advanced techniques in solar parks as to increase the overall plant efficiency.

2.1. EFFICIENCY ENHANCEMENT OF A DUAL-AXIS SOLAR PV PANEL TRACKER USING WATER-FLOW DOUBLE GLAZING TECHNIQUE

The WFDG chamber is proposed for the cooling purpose of PV Panels, and it will contain double panes of clear acrylic plastic sheets [11]. Water will be filled inside these sheets and the whole arrangement will be placed in contact with the PV Panel Surface as elaborated in Figure 7.

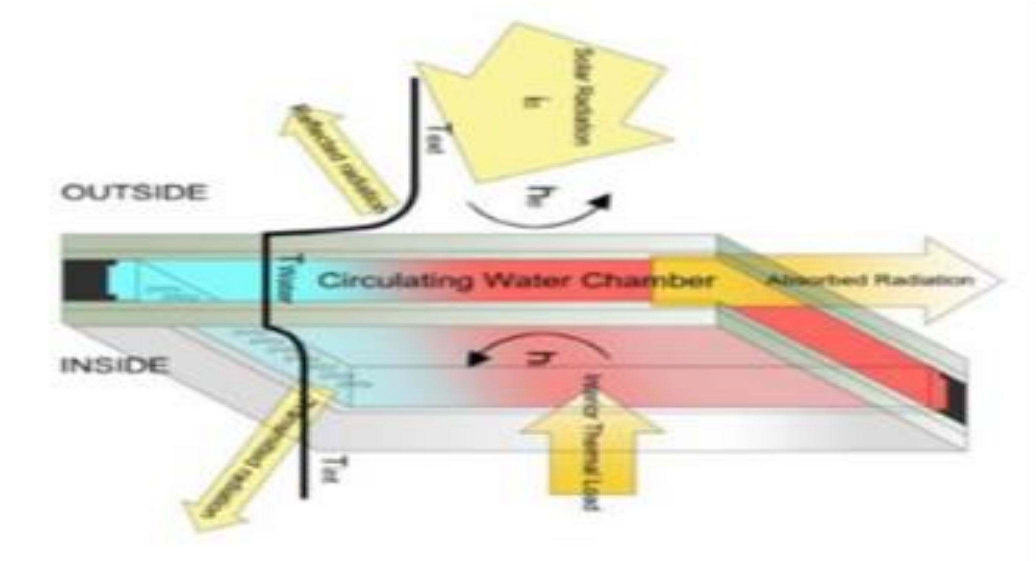


Figure 7. Thermal Performance of WFDG System

The parameters that will be considered while optimizing the WFDG will be:

- Thickness of the WFDG Chamber
- Position of WFDG Chamber
- Flow Rate of Water in WFDG Chamber

Water is circulated in the chamber with the help of DC water pump and the hot water from the chamber is cooled with the help of a basin buried inside the soil. The ground heat exchanging technique minimizes the cost for cooling the water and uses natural cooling of the soil in ground to cool the water and maintain the temperature of water flowing inside the chamber [12]. This method of cooling without using fan is low cost and consumes less electrical energy.

2.1.1. TAGUCHI OPTIMIZATION METHOD

Taguchi Optimization Method considers the control factors and levels to give the optimum combination as to optimize the design parameters of WFDG system. The orthogonal array for the control factors and realizing their impact on the output is considered in Taguchi Optimization Method.

The Technique of Double-Glazing Cooling Chamber to Enhance Overall Efficiency of PV Panel:

- Using front water-cooling chamber executes; PV panel cooling and filtering the Sun's irradiance as well as reducing its Sun light reflection falling on it.
- The average reduction in the PV panel temperature is 45.56 %, 40.12% and 50.06% with using (front, rear, and both sides) cooling chambers respectively.
- With using both sides cooling technique, the PV average electrical power and the electrical efficiency enhanced by 12.69% and 14.204% respectively.
- For every 1 degree Celsius below 25 degree the maximum solar efficiency of the panel increases by 0.38%.

2.1.2. THERMAL BEHAVIOUR OF WFDG SYSTEM

The solar radiation when reaches the WFDG chamber it is partially reflected, and the remaining useful radiation is absorbed. The water temperature rises once the absorbed radiation enters the confined chamber [13]. The proportion of the solar energy entering the chamber is the sum of the convective and the conductive heat transfers of the solar radiation. This allows to determine the transmittance factor of solar radiation on the chamber. The WFDG chamber allows to create an isothermal shield to maintain the temperature of the glazed surface of the panel's envelope less than the internal temperature. The heat is transmitted due to the temperature gradient between the Panel and the chamber. WFDG allows the transmittance of heat from the panel to the chamber with the help of temperature gradient. The thermal behaviour of WFDG chamber is elaborated in Figure 7 [14].

The total energy being absorbed per unit time by the water is the sum of energies acting in the system. The sum of energies is the (radiation energy that is being transmitted through glazing + the exchange of energy with the outer air due to forced convection or radiation + energy exchange inside the panel due to ordinary convection + absorbed Sun radiation by the glazing system) [15]. The energy per unit time absorbed Q by the water is the sum of all these energies and its unit is (W/m2).

$$Q = \dot{m}C_p(T_w - T_{ext}) = GA\alpha_w + \tau G - h_{ext}A(T_w - T_{ext}) - h_{int}A(T_w - T_{int})$$

Equation 1. Equation for calculation of Q ṁ is water mass flow rate and is denoted by kg/s. Cp is the specific heat of water J/kg.K. Tw is the water temperature in chamber. Text and Tin is the internal and the external temperature. Solar irradiance is G, and its unit is W/m2. Window surface that is directed orthogonally to the direction of Sun rays is A. aw is the absorption factor of water chamber. Solar Transmittance is denoted by τ. External and internal heat transfer coefficients are hext and hint in Equation 1.

The WFDG System:

The WFDG is composed of six components:

1. WFDG chamber
2. Water tank
3. Water pump
4. Heat exchanger
5. Inlet and outlet water pipes
6. Thermostat.

The WFDG system is explained in detail with parts clearly mentioned. Clear double panes of acrylic sheets are used to make WFDG chamber. The WFDG chamber is then filled with distilled water and is fixed in close contact with the panel. The WFDG chamber is mounted on the surface of PV Panel. It has been found out that the acrylic sheet with the thickness of 2 mm has the light permeability factor of 98.66% as compared to the light permeability factor of ordinary glass sheet that is only 92.4%. Hence this research helped to conclude that total energy transmittance factor is 6% more for acrylic sheet as compared to ordinary glass.

The acrylic sheets that are 2mm thick are ideal for the construction of the glazing chamber. The three areas of concern for the whole technique are thickness of WFDG Chamber, Position of WFDG Chamber and the Flow Rate of pumping water. There parameters play a vital role in optimization of the system using Taguchi Technique.

2.1.3. COOLING TECHNIQUE IN WFDG CHAMBER

The cold water is allowed to enter from one side of the WFDG Chamber with the help of two inlets to promote the regular distribution across the chamber and then once it absorbs the heat of the system is allowed to drain from the outlet from other side of the chamber. Water is pumped and circulated in the WFDG chamber with the help of 12V, 0.18A DC Water Pump. The water is circulated in the chamber and its flow rate is dependent on the cooling needed at a certain time in a specific area.

The heat that is captured by the WFDG Chamber is then transported to water tank for the reduction of thermal oscillations in glass panes due to solar radiation. The hot water of the tank is then pumped into heat exchanger for cooling [16]. The cold water is then again supplied to the WFDG Chamber where it is used to absorb the heat of the PV Panels and maintaining the temperature. The heat exchanger is buried in the mud filled basin that is used to cool the water passing through it. The idea of mud filled basin is derived from the technique of ground heat exchangers. Ground heat exchangers consume less electricity because no fan is needed to cool the circulating water. The temperature of water can be reduced to 25-30 degree centigrade with the help of ground heat exchanger technique therefore WFDG system can be considered as one of the successful tools to cool the temperature of PV Panels.

2.2. RESEARCH GAP

- The literature survey highlighted that different author had their own understanding regarding the optimization of solar panels efficiency and proposed different techniques for the optimization of efficiency in PV panels but the technique I proposed will be WFDG and it will work on the basic principle of water flow in the acrylic box that will be mounted on the solar panel, and it will be a cost effective project because this technique does not requires huge amount of investment.
- The previous implemented techniques for severe weather conditions in PV panels are not customer friendly because they require a lot of machinery as well as it is a costly alteration, but the technique I proposed will be cheap and accessible to all the customers of solar panels and those who are interested in optimizing the efficiency of their PV Plant.
- Taguchi Optimization Method will help in the prediction of thickness of acrylic box and the distance of box from the panel additionally flow rate of water in the acrylic box to limit the temperature is also predicted with the help of Taguchi Optimization Method.
- This will help in the optimization of the electrical efficiency of PV Panels by an efficient technique named as “WFDG”.

2.3. MAIN CONTRIBUTIONS

- Maximizing the overall plant capacity and proposing a model to be adopted in future projects.
- Highlighting the present flaws of the system that lead to the disastrous outcomes from

QASP.

- System Design Improvement can be done by observing the knowledge as presented in this report.
- Improving the overall working of the Plant and reduction in overall cost of electricity by enhancing the production capacity.
- More Stable Installation of the Solar Parks with a promising deal of constant energy in future.
- Promotion of Green and Clean Form of Energy and a healthier future of the Nation.
- Provides the basic information to make remarkable impact on the overall renewable energy sector and gain massive profit in terms of electricity production.

CHAPTER 3

METHODOLOGY

CHAPTER 3

3. METHODOLOGY

The simulation is made in SimScale tool that is available online for designing glass chamber and seeing the effect of temperature control on the PV Panel. The overall increased efficiency due to WFDG is then recorded in a tabular format and graphical outcomes are shown in the results section of this report. Simulation results are also shared in this report.

3.1. COOLING TECHNIQUE IN WFDG CHAMBER:

The cold water is allowed to enter from one side of the WFDG Chamber with the help of two inlets to promote the regular distribution across the chamber and then once it absorbs the heat of the system is allowed to drain from the outlet from other side of the chamber. Water is pumped and circulated in the WFDG chamber with the help of 12V, 0.18A DC Water Pump. The water is circulated in the chamber and its flow rate is dependent on the cooling needed at a certain time in a specific area.

The heat that is captured by the WFDG Chamber is then transported to water tank for the reduction of thermal oscillations in glass panes due to solar radiation. The hot water of the tank is then pumped into heat exchanger for cooling [17]. The cold water is then again supplied to the WFDG Chamber where it is used to absorb the heat of the PV Panels and maintaining the temperature. The heat exchanger is buried in the mud filled basin that is used to cool the water passing through it. The idea of mud filled basin is derived from the technique of ground heat exchangers. Ground heat exchangers consume less electricity because no fan is needed to cool the circulating water. The temperature of water can be reduced to 25-30 degree centigrade with the help of ground heat exchanger technique therefore WFDG system can be considered as one of the successful tools to cool the temperature of PV Panels.

The circulation and the amount of cold water to be supplied in the WFDG chamber is controlled with the help of a thermostat that is adjustable and is set to 40 degrees centigrade. Once the temperature of the panel rises to 40 degrees centigrade the mechanism is triggered and the cold water starts circulating in the WFDG Chamber via the inlets provided to feed the cold water inside the WFDG Chamber.

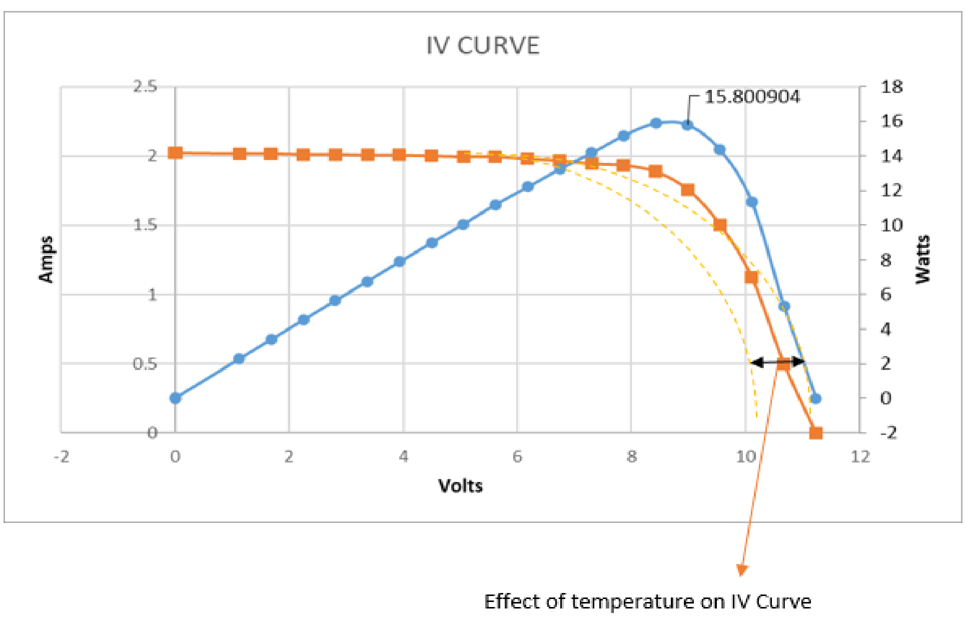


Figure 8 Effect of Temperature on IV Curve

Every Single Panel that is produced in the factory has its own IV characteristics depending on the temperature. The higher the temperature the more left the curve will be and this will eventually mean smaller product of I*V resulting in less power. The technique of WFDG allow pushing the curve to the right-hand side to increase the multiplication of I*V that means greater power, therefore WFDG technique is used to keep the temperature in the optimum range for maximum efficiency of solar panel (25-35 ^{o}C).

3.1.1: SOLAR PV PANEL SPECIFICATIONS

Parameter	**Value**
Type	Mono-Si
Rated maximum power, Pmax	28W
Operating voltage, Vmp	21V
Operating current, Imp	1.33A
Open-circuit voltage, VOC	23.12V
Short-circuit current, ISC	1.515A
Efficiency, ηele	15 %
Weight	2.5 kg
Dimensions	43×42×2.4 cm

Table 2 Solar PV Panel Specifications

Table 2 is the Solar PV Panel Specifications that is used in this research to perform the experimentation. The WFDG technique is applied on this PV Panel to see the enhanced electrical output of the panel. At the end of the research the improved results with WFDG are compared with non-WFDG arrangement to prove the validity of my research.

3.1.2: SIMULATION MODELLING

Software Used: SimScale

SimScale is an efficient software product which deals in Computer Aided

Engineering (CAE). It was developed by SimScale GmbH for the analysis of finite elements, thermal simulations, and computational fluid dynamics [18].

3.1.3. SIMULATED MODEL

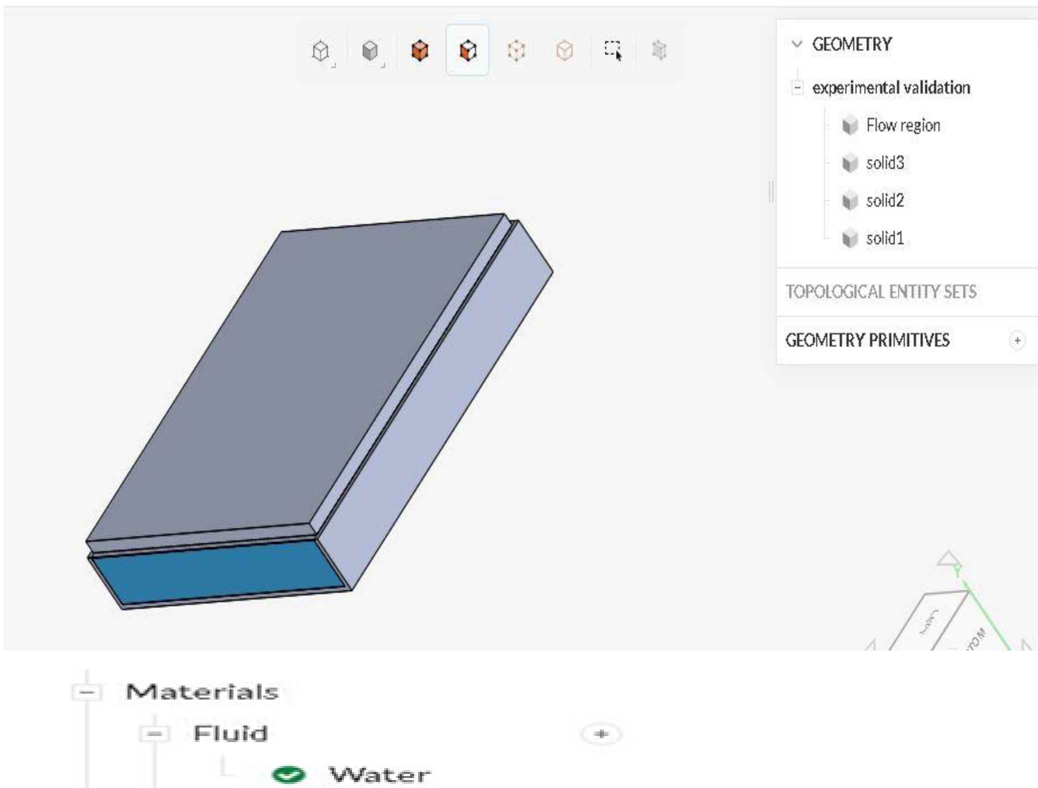


Figure 9. Software designed model of Glass Chamber used in WFDG

Figure 8 shows the software designed model of Glass Chamber that is used in WFDG technique by using SimScale Software. The glass chamber is hollow from inside to provide the steady flow of water and the contact area of Glass Chamber with PV Panel is kept maximum to provide efficient cooling of the PV Panel.

3.2. DETAILED VIEW OF THE GLASS CHAMBER DESIGNED FOR WFDG

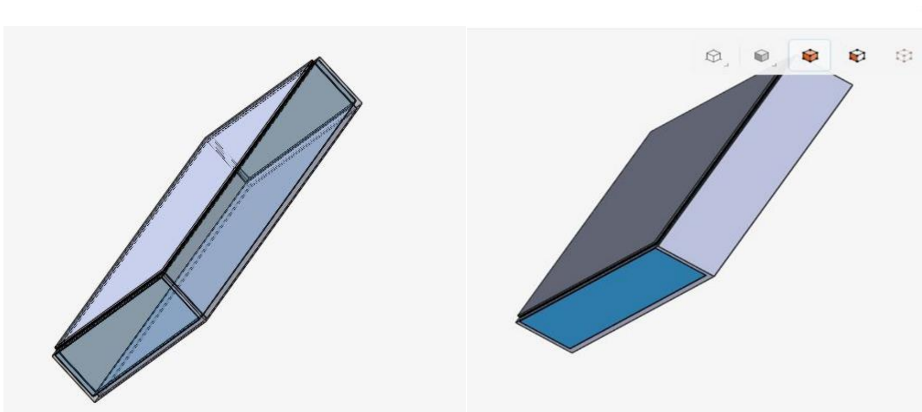


Figure 10. Detailed View of Glass Chamber Designed for WFDG

The Glass Chamber that will be used for the implementation of WFDG Cooling Technique on PV Panels is simulated in the software with the help of SimScale as shown in Figure 8 and 9. The Software allowed testing the parameters involved in the development of WFDG technique and verifies that the technique can efficiently maintain the temperature of PV Panels for the optimum range of operation under hot weather conditions [19][20].

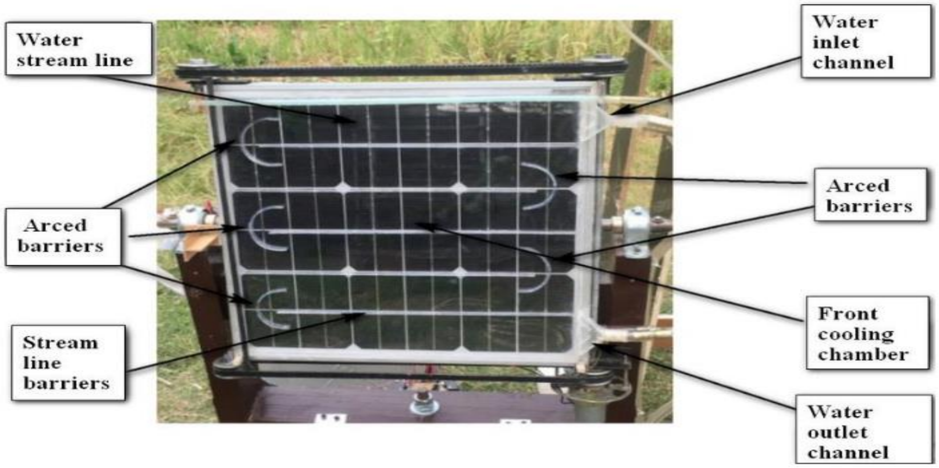


Figure 11. Mechanical Modelling of WFDG

The cold water is allowed to enter from one side of the WFDG Chamber with the help of two inlets to promote the regular distribution across the chamber and then once it absorbs the heat of the system is allowed to drain from the outlet from other side of the chamber. Water is pumped and circulated in the WFDG chamber with the help of 12V, 0.18A DC Water Pump. The water is circulated in the chamber and its flow rate is dependent on the cooling needed at a certain time in a specific area as shown in Figure 10.

The heat that is captured by the WFDG Chamber is then transported to water tank for the reduction of thermal oscillations in glass panes due to solar radiation. The hot water of the tank is then pumped into heat exchanger for cooling. The cold water is then again supplied to the WFDG Chamber where it is used to absorb the heat of the PV Panels and maintaining the temperature. The heat exchanger is buried in the mud filled basin that is used to cool the water passing through it. The idea of mud filled basin is derived from the technique of ground heat exchangers. Ground heat exchangers consume less electricity because no fan is needed to cool the circulating water. The temperature of water can be reduced to 25-30 degree centigrade with the help of ground heat exchanger technique therefore WFDG system can be considered as one of the successful tools to cool the temperature of PV Panels [21].

The circulation and the amount of cold water to be supplied in the WFDG chamber is controlled with the help of a thermostat that is adjustable and is set to 40 degrees centigrade. Once the temperature of the panel rises to 40 degrees centigrade the mechanism is triggered and the cold water starts circulating in the WFDG Chamber via the inlets provided to feed the cold water inside the WFDG Chamber [22] [23].

CHAPTER 4

RESULTS AND DISCUSSION

CHAPTER 4

4. RESULTS AND DISCUSSIONS

This section deals with the results of the simulated technique and its usage in maintaining the temperature of the PV Panel at an optimum range for the efficient power output of the PV Panel. The PV panel whose temperature is maintained under safe operational limit can produce the rated power with more efficiency as compared to those PV Panels whose temperature is not controlled. The figures given below will provide the controlled outputs in form of temperature, pressure and velocity of the fluid flowing inside the glass chamber in WFDG technique.

4.1. SIMULATION RESULTS

The results of the simulation shown below highlights the importance of WFDG in maintaining the temperature of PV Panel for electrical optimization of the PV Panel. The results clarified the fact that if WFDG is applied to the conventional PV Panel arrangement then the optimization PV Panel can be done easily for any type of severe external hot temperatures. The solution to the internal temperature of the PV Panel is shown with the help of results which help in achieving and maintaining the PV Panel temperature for optimum operational range (30-35) ^{o}C. The velocity of the water to be flown inside the glass chamber is also shown in the simulated results and the optimized temperature for optimum production of electrical energy from solar panels is also shown with the help of results.

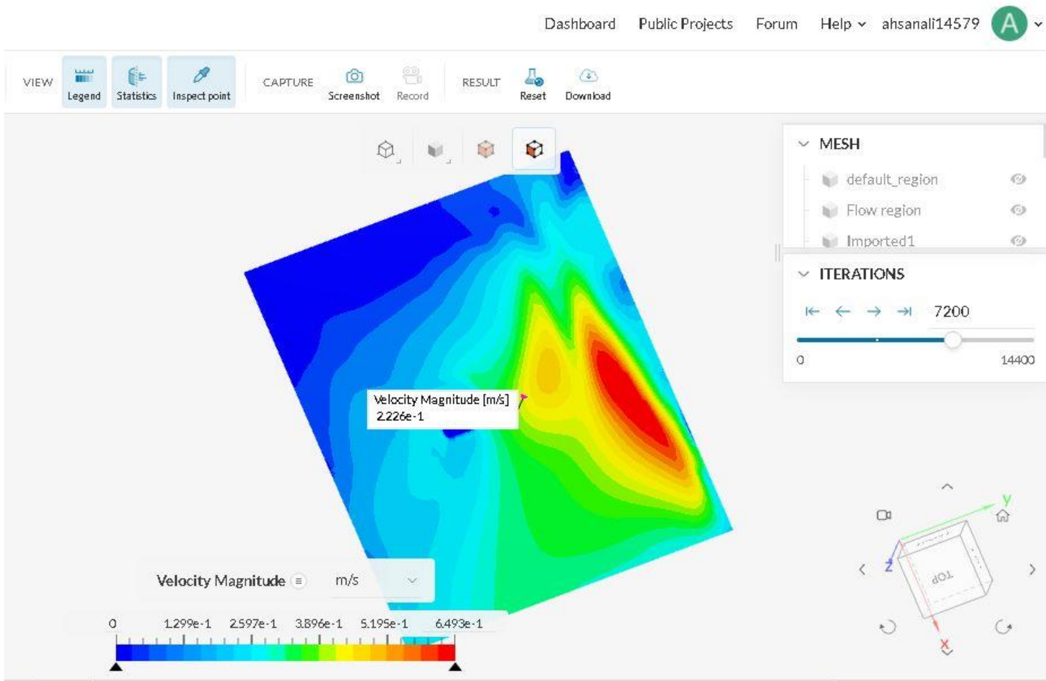


Figure 12. Velocity Magnitude of the Fluid in WFDG Simulation

This screenshot from the SimScale simulation helps in understanding the flow rate as the number of iterations proceed throughout daytime. The Velocity Magnitude of the Fluid in a WFDG Simulation is shown in Figure 11.

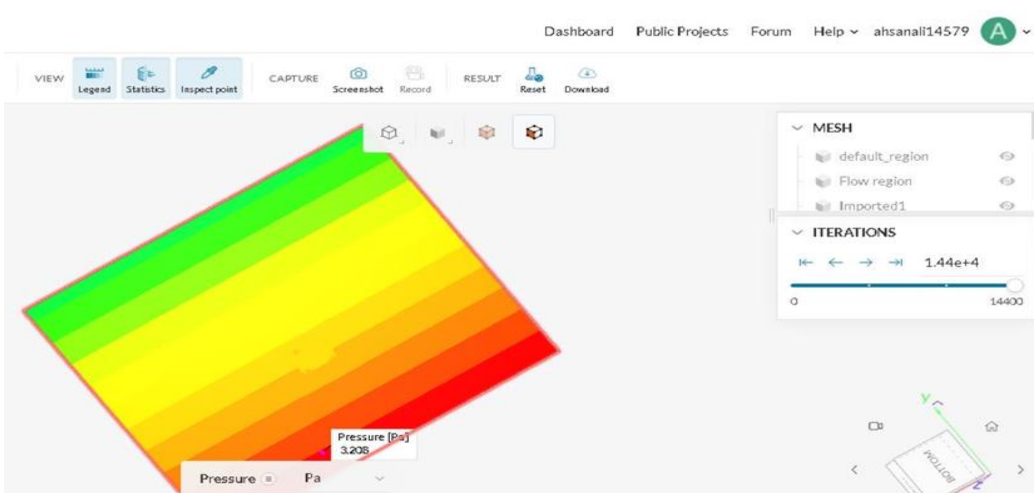


Figure 13. Pressure Constraints of WFDG Simulation

Figure 12 shows the pressure that exerted on the PV Panel and the Glass chamber due to flow rate of water that is available inside the glass chamber for cooling purpose. The pressure experienced by the PV Panel and the Glass box helps in designing of the glass box so that it can easily bear the pressure constraints while being in the system.

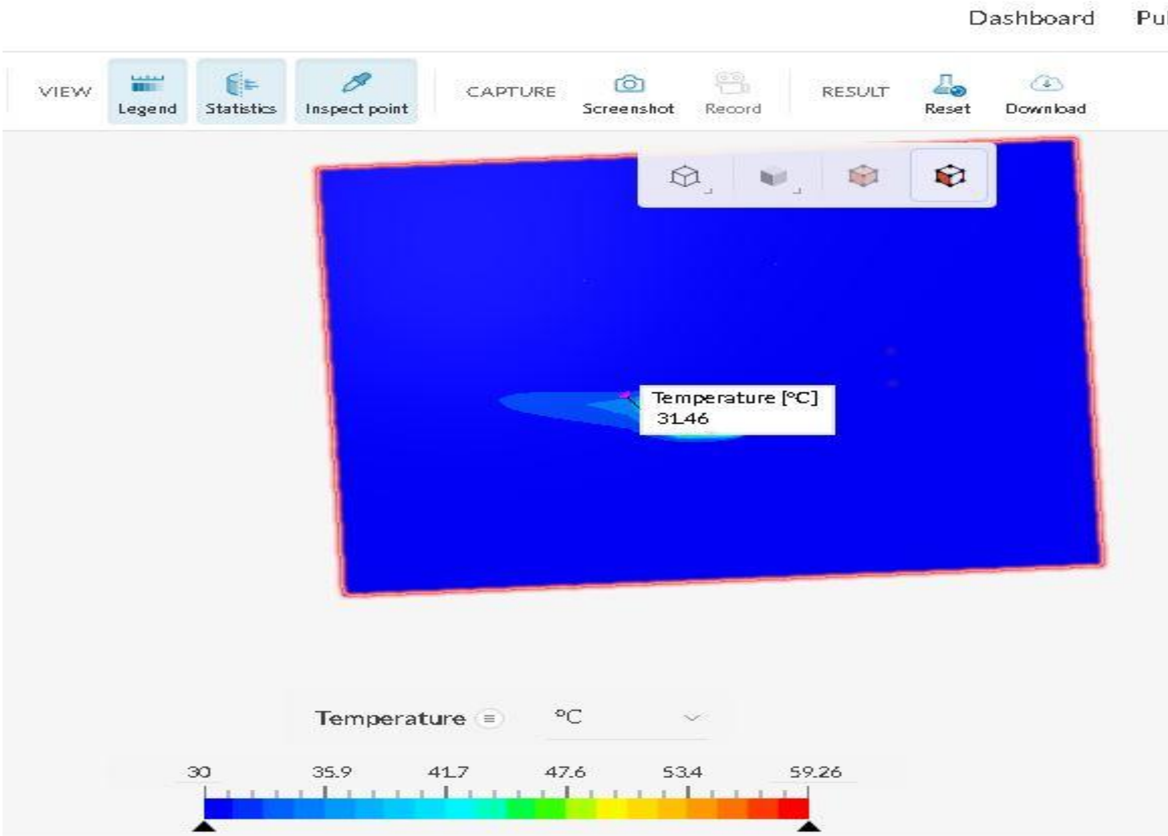


Figure 14. PV Panel’s Temperature achieved for optimum performance at 31.46 °C with the help of WFDG Technique

In Figure 13 it is shown that with the help WFDG Technique, I succeded in achieving the temperature limit of (30-35) ^{o}C in hot summer days of June for the optimum performance of PV Panels and to prevent the PV Panels from degradation factor of per degree rise above the operational range. I succeeded in achieving optimum temperature range for the PV Panel to perform excellently under the rated temperature values.

4.1.1. TEMPERATURE CONTROL OF PV PANEL DURING DAY TIME WITH WFDG VS TEMPERATURE RISE OF PV PANEL WITHOUT WFDG (10 JUNE 2021, KHUSHAB)

Time	PV Panel Temperature With WFDG	PV Panel Temperature Without WFDG
7:00 AM	27°C	32°C
7:30 AM	27.5°C	34°C
8:00 AM	28.5°C	34°C
8:30 AM	29°C	35°C
9:00 AM	30°C	35.5°C
9:30 AM	30°C	37°C
10:00AM	30°C	40°C
10:30 AM	30.5°C	40°C
11:00 AM	30.5°C	45°C
11:30 AM	31°C	47°C
12:00 PM	32.3°C	52°C
12:30 PM	32.4°C	53°C
1:00 PM	32.45°C	53.5°C
1:30 PM	32.5°C	54°C
2:00 PM	32°C	54°C
2:30 PM	32°C	54°C
3:00 PM	31.5°C	53.5°C
3:30 PM	31°C	52°C
4:00 PM	31°C	49°C
4:30 PM	30°C	46°C
5:00 PM	30°C	43°C
5:30 PM	30°C	41°C
6:00 PM	29°C	39°C
6:30 PM	29°C	35°C
7:00 PM	28°C	35°C

Table 3 Temperature Maintaining of PV Panel During Day Time with WFDG vs Temperature Rise of PV Panel without WFDG (10 June 2021, Khushab)

Table 3 enlists the temperature that is achieved in a functional arrangement of PV Panel during the experimentation and contrasted these temperature values with non-WFDG arrangement. Results showed that with WFDG technique the temperature values remained in the rated temperature range and thus PV Panel optimization is done with WFDG.

4.1.2. PANEL OUTPUT POWER THROUGH DAYTIME WITH WFDG VS WITHOUT WFDG (10 JUNE 2021, KHUSHAB)

Time	**Output Power With WFDG**	**Output Power Without WFDG**
7:00 AM	13 W	11 W
7:30 AM	17 W	15 W
8:00 AM	19 W	17 W
8:30 AM	23 W	20 W
9:00 AM	24 W	22 W
9:30 AM	25 W	23 W
10:00AM	26 W	23 W
10:30 AM	26 W	23.5 W
11:00 AM	26 W	24 W
11:30 AM	27 W	24.5 W
12:00 PM	27 W	25 W
12:30 PM	27.5 W	25 W
1:00 PM	28 W	26 W
1:30 PM	28 W	26 W
2:00 PM	28.5 W	26 W
2:30 PM	28 W	26.5 W
3:00 PM	26 W	24 W

3:30 PM	23 W	22 W
4:00 PM	20 W	18 W
4:30 PM	15 W	14 W
5:00 PM	10 W	9 W
5:30 PM	5 W	4 W
6:00 PM	3 W	2 W
6:30 PM	2 W	0 W
7:00 PM	0 W	0 W

Table 4 Panel Output Power through daytime With WFDG vs Without WFDG (10 June 2021, Khushab)

Table 4 enlists the Panel Output Power throughout daytime with WFDG Technique and without-WFDG Technique. It is evident from the values of the table that the PV Panel's electrical efficiency is enhanced by using WFDG, WFDG helped in maintaining the operational temperature ranges for optimum production of electricity in the desired arrangement.

Time	**PV Panel Temperature With WFDG (°C) Monday**	**PV Panel Temperature Without WFDG(°C) Monday**	**PV Panel Temperature With WFDG (°C) Tuesday**	**PV Panel Temperature Without WFDG(°C) Tuesday**	**PV Panel Temperature With WFDG (°C) Wednesday**	**PV Panel Temperature Without WFDG(°C) Wednesday**	**PV Panel Temperature With WFDG (°C) Thursday**	**PV Panel Temperature Without WFDG(°C) Thursday**
7:00 AM	27	32	25	33	26	32	25	32
7:30 AM	27.5	34	26	32	26	32	26	34
8:00 AM	28.5	34	27	35	26	35	27	34
8:30 AM	29	35	30	36	27	36	27	35
9:00 AM	30	35.5	31	36	28	37	30	35.5
9:30 AM	30	37	31.5	37	28	38	32	37
10:00AM	30	40	31	42	31	42	32	40
10:30 AM	30.5	40	30	43	30	42	33	40
11:00 AM	30.5	45	32	46	30	46	34	45
11:30 AM	31	47	32	47	31	50	34	47

12:00 PM	32.3	52	32	55	34	54	34	52
12:30 PM	32.4	53	34	56	34	58	32	53
1:00 PM	32.45	53.5	34	57	34	59	33	53.5
1:30 PM	32.5	54	34	58	35	58	35	54
2:00 PM	32	54	32	56	33	57	35	54
2:30 PM	32	54	34	56	33	57	35	54
3:00 PM	31.5	53.5	31	54	33	56	34	53.5
3:30 PM	31	52	30	53	32	55	32	52
4:00 PM	31	49	31	50	32	54	30	49
4:30 PM	30	46	30	51	30	50	31	46
5:00 PM	30	43	32	46	29	49	30	43
5:30 PM	30	41	31	45	29	39	29	41
6:00 PM	29	39	30	43	28	35	26	39
6:30 PM	29	35	30	42	27	32	25	35
7:00 PM	28	35	27	41	27	32	22	35

Table 5 Results for Temperature Maintaining with WFDG vs without-WFDG for weekdays (10 June to 14 June)

Table 5 shows the results that are obtained while maintaining the temperature range with WFDG vs Without-WFDG in weekdays. The weekdays that are considered from experimentation are Monday to Thursday (10 June to 14 June) respectively. The results are in ^{o}C.

Time	Output Power With WFDG in Watts (W) Monday	Output Power Without WFDG in Watts (W) Monday	Output Power With WFDG in Watts (W) Tuesday	Output Power Without WFDG in Watts (W) Tuesday	Output Power With WFDG in Watts (W) Wednesady	Output Power Without WFDG in Watts (W) Wednesday	Output Power With WFDG in Watts (W) Thursday	Output Power Without WFDG in Watts (W) Thursday
7:00 AM	13	11	12	12	14	10	12	11
7:30 AM	17	15	16	16	18	13	14	15
8:00 AM	19	17	18	17	15	15	15	17

8:30 AM	23	20	22	22	25	17	20	20
9:00 AM	24	22	24	23	25	20	22	22
9:30 AM	25	23	26	23	26	22	22	23
10:00AM	26	23	25	24	27	24	25	23
10:30 AM	26	23.5	26	23	27	24	25.5	23.5
11:00 AM	26	24	27	23	27	25	26	24
11:30 AM	27	24.5	27	24	28	25	26	24.5
12:00 PM	27	25	28	24	27	26	26	25
12:30 PM	27.5	25	27	25	28	27	27	25
1:00 PM	28	26	28	26	29	27	28	26
1:30 PM	28	26	29	27	29	27	27	26
2:00 PM	28.5	26	29	27	28	26	25	26
2:30 PM	28	26.5	29	27	26	25	26	26.5
3:00 PM	26	24	28	23	23	25	27	24
3:30 PM	23	22	27	22	22	23	27	22
4:00 PM	20	18	25	16	21	19	22	18
4:30 PM	15	14	17	15	16	15	16	14
5:00 PM	10	9	12	8	9	8	9	9
5:30 PM	5	4	11	3	4	3	4	4
6:00 PM	3	2	10	4	5	0	3	2
6:30 PM	2	0	6	2	4	0	2	0
7:00 PM	0	0	4	2	0	0	0	0

Table 6 Output Power in Watts with WFDG and Without WFDG for Weekdays (10 June to 14 June)

Table 6 enlists the results that are obtained from 10th June to 14th June in terms of Output Power with WFDG and without-WFDG. The outputs showed that there is an increase in the electrical efficiency of the PV Panel if the temperature is maintained in the ideal operational range of the PV Panel. Table 6 makes it evident that the output power of the PV Panel is optimized with the help of WFDG Technique.

4.1.3. GRAPHICAL OUTCOMES

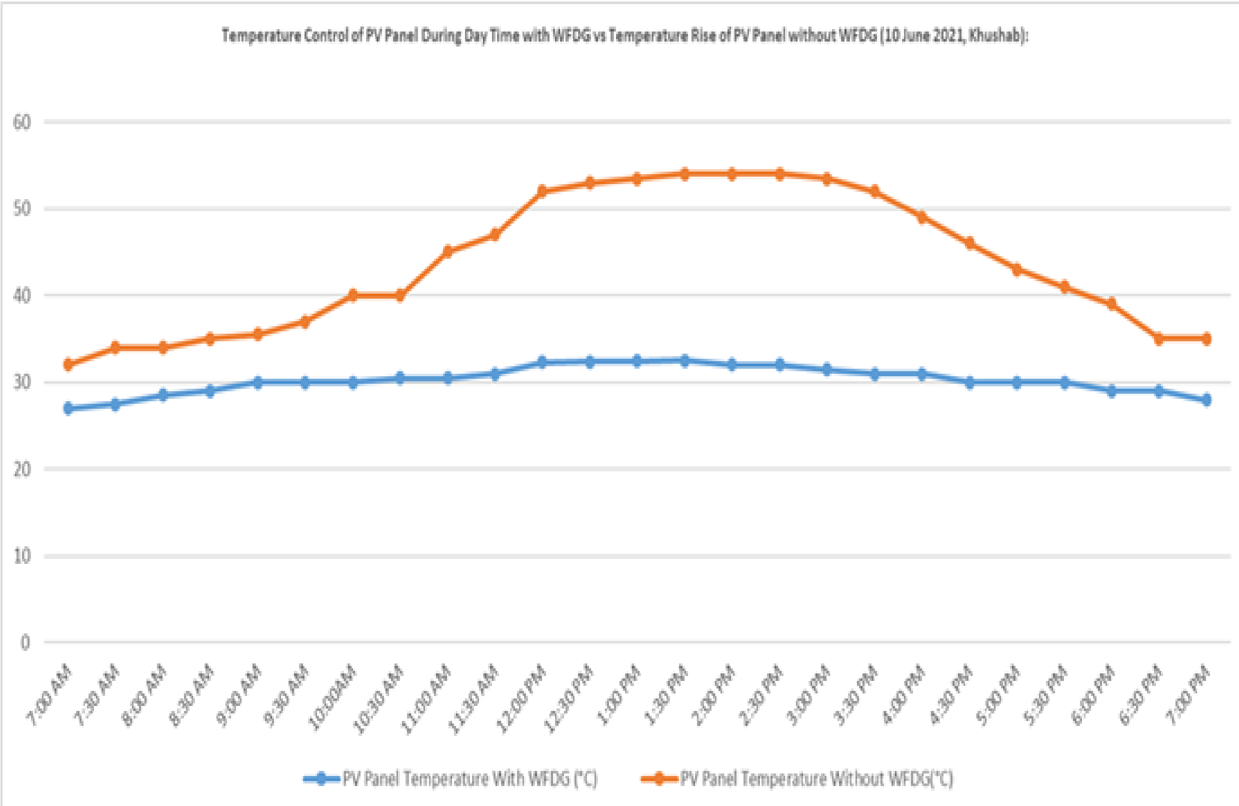


Figure 15. Temperature maintaining of PV Panel During Day Time with WFDG vs Temperature Rise of PV Panel without WFDG (10 June 2021, Khushab)

Figure 14 makes it clear that by using WFDG, the maximum upper limit of the Panel's temperature does not exceed 35 degree that is a good sign for optimization of PV Panel's electrical output. The temperature range does not exceed from the optimal values for maximum production of electrical energy (30-35) degree centigrade thus minimum/no-degradation is observed by WFDG in terms of temperature and its effect on electrical efficiency of PV Panel.

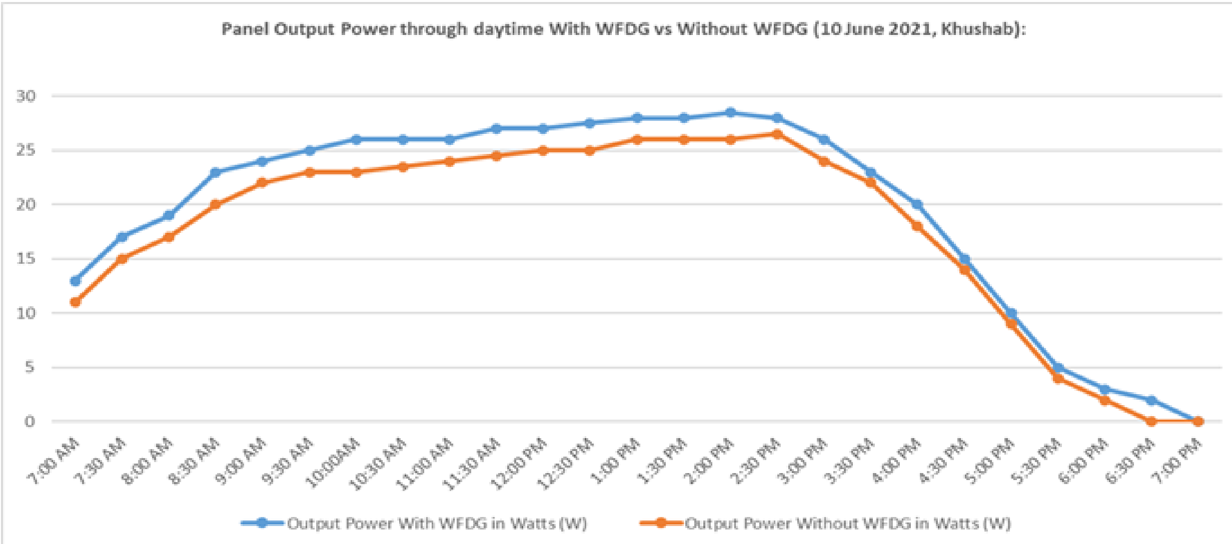


Figure 16. Panel Output Power through daytime With WFDG vs Without WFDG (10 June 2021, Khushab)

It is a record of Output Power of PV Panel with WFDG and Without-WFDG per hour, the values in Figure 15 make it clear that by using WFDG technique the electrical output power of PV Panel is optimized.

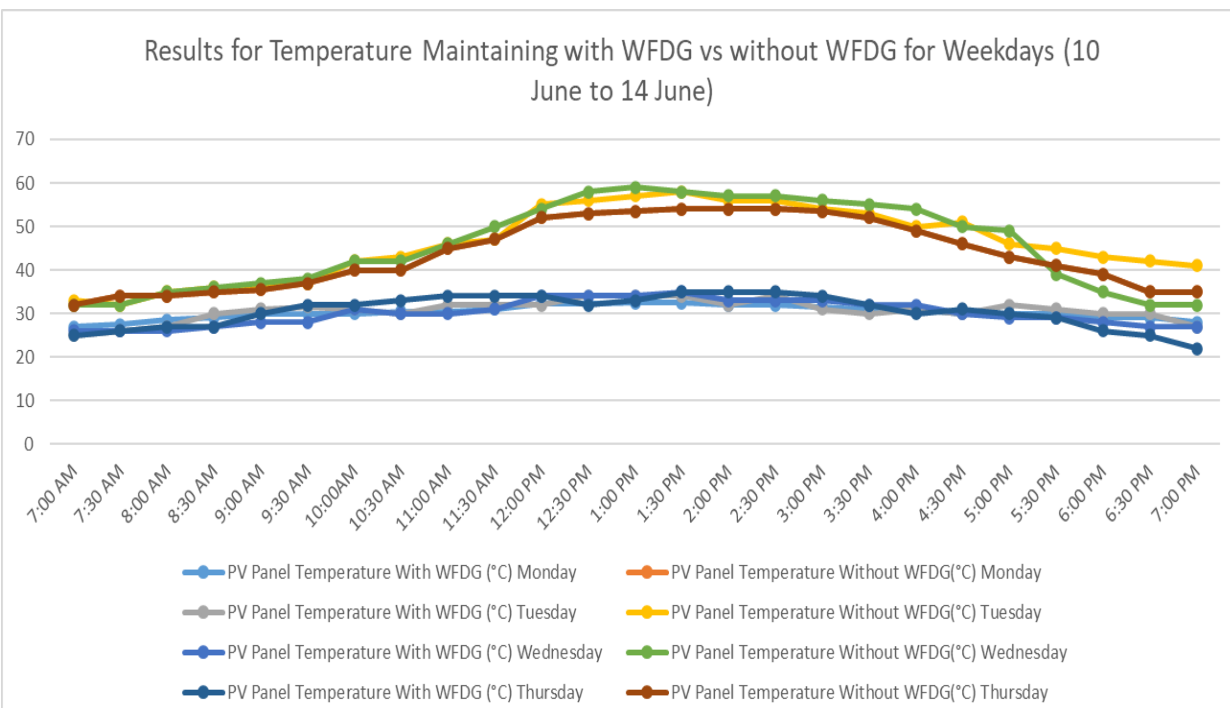


Figure 17. Results for Temperature Maintaining with WFDG vs without-WFDG for weekdays (10 June to 14 June)

In figure 16 temperature results for weekdays are given using WFDG vs without WFDG from (10th June to 14th June), it is displayed by blue lines that for with WFDG the temperature of PV Panel remained in rated optimum operational range for maximum electrical efficiency.

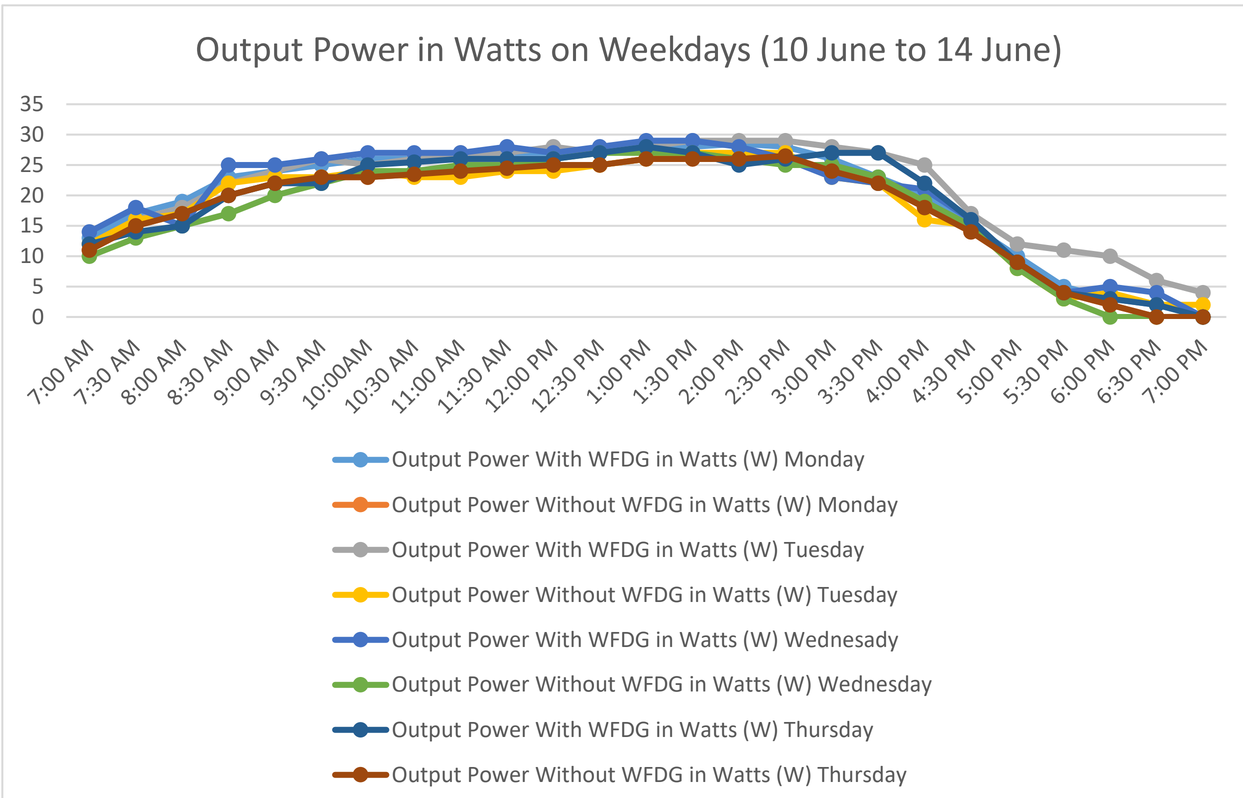


Figure 18. Results for Output Power in Watts with WFDG and Without WFDG for Weekdays (10 June to 14 June)

Figure 17 shows the hourly performance comparison of the Output Power in Watts with WFDG vs Without-WFDG. The results from the graph showed that the electrical efficiency with WFDG is greater than the electrical efficiency without WFDG. Weekdays considered for this graph are Monday to Thursday (10th June to 14th June).

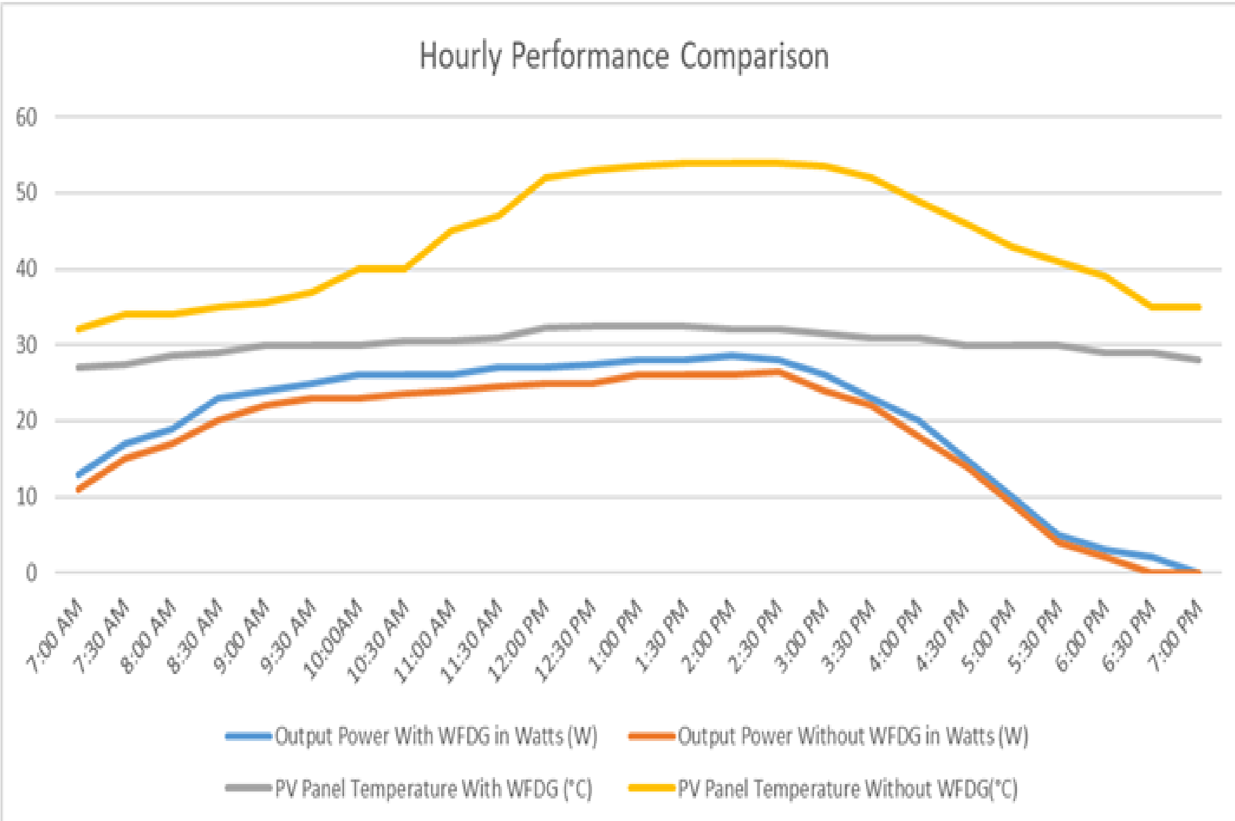


Figure 19. Hourly Performance Comparison

This is an hourly performance comparison of the Output Power with WFDG vs Without-WFDG and PV Panel's Temperature with WFDG vs PV Panel's Temperature Without-WFDG.

CHAPTER 5

CONCLUSION AND FUTURE WORK

CHAPTER 5

5. CONCLUSION AND FUTURE WORK

5.1. CONCLUSION

This research focused on the technique of water flow double glazing to enhance the electrical efficiency of solar panels. Taguchi technique was used to optimize the performance of PV panels. The results extracted from this research are:

• This WFDG technique consumes less amount of water for cooling as well as low electrical energy is needed to power up the cooling mechanism.

• The cooling chamber can be used as a filter for incident Sun's light, and it also improves the efficiency of solar panel.

• The necessary findings such as optimum chamber thickness of 1.5cm and water flow rate 28.2 cm3/sec in WFDG.

• 0cm distance of glazing chamber from PV Panel surface. Position factor of Glazing Chamber.

• Maintaining the PV Panel Temperature (30-35) ^{o}C for maximum efficiency.

5.2. FUTURE WORK

- The proposed technique can be applied to the PV Plants across Pakistan to increase the electrical efficiency of the PV Panels.
- The overall enhancement can contribute to the research field that is performed globally to help renewables grow and optimize.
- In future the thesis can be improvised by investigating the impacts of other cooling techniques for the optimal operation of PV Plants.

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