Impact of Temperature & Illumination for Improvement in Photovoltaic System Efficiency

By

Farrukh Javed
2013-MS-ENR-20

Supervisor

Dr. Fahim Gohar Awan
Assistant Professor
EED, UET KSK

CENTRE FOR ENERGY RESEARCH & DEVELOPMENT

UNIVERSITY OF ENGINEERING & TECHNOLOGY

LAHORE, PAKISTAN

December 2018

IMPACT OF TEMPERATURE & ILLUMINATION FOR IMPROVEMENT IN PHOTOVOLTAIC SYSTEM EFFICIENCY

BY

FARRUKH JAVED

2013-MS-ENR-20

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF SCIENCE

IN

ENERGY ENGINEERING

THESIS SUPERVISOR:

DR. FAHIM GOHAR AWAN

ASSISTANT PROFESSOR

EED, UET KSK

CENTRE FOR ENERGY RESEARCH & DEVELOPMENT

UNIVERSITY OF ENGINEERING AND TECHNOLOGY LAHORE

December 2018

IMPACT OF TEMPERATURE & ILLUMINATION FOR IMPROVEMENT IN PHOTOVOLTAIC SYSTEM EFFICIENCY

By

FARRUKH JAVED

2013-MS-ENR-20

Thesis Supervisor ________________________

Signature/Date

External Examiner ________________________

Signature/Date

Director/Chairman ________________________

Signature/Date

Dean ________________________

Signature/Date

CENTRE FOR ENERGY RESEARCH AND DEVELOPMENT

UNIVERSITY OF ENGINEERING & TECHNOLOGY, LAHORE

December 2018

ABSTRACT

This research endeavors to boost up the annual power production as well as efficiency of photovoltaic (PV) systems by investigating the combined effect of temperature and illumination, as these both have a significant impact on PV systems output power.

This proposed approach combines solar radiation tracker system and choice of the best suitable PV module in terms of radiation harvesting and power production using Rhino/Grasshopper. The solar radiation tracker system is used to track the sun for optimal amount of radiations depending on the annual weather data available for Pakistan. This system is studied for horizontal, vertical and dual axis trackers. Furthermore, it is found that, this technique is very useful to boost the power production in most of the months of year as compared to fixed PV system approach. On the other hand, selection of best PV module type intends to achieve better efficiency. It is shown in results that California Energy Commission (CEC) module and Sandia module outperform conventional simplified silicon crystalline module in term of radiation harvesting and power production. This suggested integration of solar radiation tracker system along with optimum PV module results in 20% annual power production improvement for the case of Pakistan.

Keywords: Photovoltaic system, Temperature, Illumination, Rhino/Grasshopper, Energy Efficiency

UNDERTAKING

I certify that research work titled "*Impact of Temperature & Illumination for Improvement in Photovoltaic System Efficiency*" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/referred.

Farrukh Javed

2013-MS-ENR-20

ACKNOWLEDGMENT

I would really like to express my deepest gratitude to my Thesis Supervisor Dr. Fahim Gohar Awan, for his excellent guidance, patience and for his ever-ready attitude to render help even when he is busy with many other very important things.

I am thankful to the staff of the Centre of Energy Research and Development (CERAD), University of Engineering and Technology Lahore for valuable guidance and support to complete this work. I am grateful to my parents, my siblings and my entire family for their profound love, care, and support.

Above all, I will like to thank the Almighty Allah & his Messenger Hazrat Muhammad (PBUH), for their love and grace without which it would be impossible for me to have achieved any educational success let alone finishing this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

PV = Photovoltaic

MPP = Maximum Power Point

STC = Standard Temperature Condition

3D = Three Dimensional

V_{OC} = Open Circuit Voltage

I_{SC} = Short Circuit Current

FF = Fill Factor

SPV = Solar Photovoltaic

SPS = Solar Photovoltaic System

CAD = Computer Aided Design

CEC = California Energy Commission

KW = Kilo Watt

MPPT = Maximum Power Point Tracker

AC = Alternating Current

DC = Direct Current

CHAPTER 1

INTRODUCTION

1.1 Background

This universe is stepping towards a crisis of electric power due to increasing demands of electric energy. There is a fast increase in energy demand comparing to energy generation. Fossil fuel resources are continuously depleting. However, we have not taken enough safety measures to deal with a possible future energy crisis. Prices of oil and gas fuels have already raised to the alarming situation and with every passing day, it is feared that these resources may be died out very soon. Therefore, the cost of these resources is a big concern and it is swiftly increasing due to an escalating shortage of these energy assets and non-availability of new resources.

The solution to this problem can be fulfilled by using renewable energy resources like solar, water etc. This renewable energy is a far better option comparing with conventional energy in many ways like cost, reliability, pollution and the most important that these resources will not deplete with the passage of time. The most important renewable energy source to fulfill the need of energy for the future is solar photovoltaic technology as the sun is the most reliable and renewable energy source because it will be available until Day of Judgment.

Solar Energy is an important energy resource due to its easy availability, cheapness, and cleanness. In these days, solar energy is getting more attention due to its technology that is developing rapidly. It has a strong capacity to meet energy demands of modern developing society and it can be used in various purposes like domestic & industrial water heating, drying of products, production of power and so on.

Solar energy may be harnessed by two ways from solar irradiations; one is called thermal system, which converts solar irradiation into thermal energy to heat working fluid while the second type is a solar photovoltaic.

Solar photovoltaic directly converts the solar illumination into electrical energy. A photovoltaic (PV) cell is made from semiconductor materials and the photovoltaic panel is incorporated by assembling these photovoltaic cells. When the irradiations of sun strike on the surface of the solar PV cell/module, it is converted into electricity.

1.2 Inspiration

Energy is a basic and useful need of human being from the very first day. There are many forms of energy that peoples use to bring easiness in life and these energy forms can be converted from one form to another form. There are mainly two types of energy resources. One is called conventional energy resource while other is called non-conventional energy resource.

Mostly, conventional energy resources like oil, gas, etc. fulfill energy needs but with the passage of time, these resources are being depleted. Moreover, these resources cause emission of dangerous gases while burning and due to which ecosystem of this universe disturbs. Therefore, it is the utmost need of time that such resources must be used that are not depleting with time and it is supporting the ecosystem of this universe.

The solution to this problem can be fulfilled by using renewable energy resources like solar, water etc. This renewable energy is a far better option comparing with conventional energy in many ways like reliability, cost, pollution and the most important that these resources will not deplete with the passage of time. The most important renewable energy source to fulfill the need of energy for future is solar photovoltaic technology as the sun is most reliable and renewable energy source because it will be available until Day of Judgment.

Solar Technology has the following advantages as compared to other conventional sources.

- It is a clean and noiseless source of energy.
- It has a low operating and maintenance cost.
- It has good reliability and performance.
- It is environment-friendly and does not produce any radioactive materials.
- Solar irradiations of the sun are readily available almost for the whole year.

1.3 Objective

Temperature and illumination have a strong impact on photovoltaic systems output power. When the irradiations of sun strike on the surface of the solar PV system, it is converted into electricity. All these irradiations do not convert into electricity as some part of these irradiations are transformed into heat, which causes to increase the temperature of the solar panel. This phenomenon becomes more prominent in summer. It is observed that above Standard Test Conditions (STC), the efficiency of the photovoltaic system decreases with the increase of temperature.

The main goal of this research is to get maximum power from a photovoltaic system. To get this maximum power, it is very important that the photovoltaic system function at the maximum power point. Location of extreme powerpoint varies with illumination and temperature [1] [2].

In this thesis, modeling of a single photovoltaic cell incorporating its working equations and considering cell temperature and illumination as the combined effect is carried out.

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

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

1.4 Problem Statement

A photovoltaic panel is incorporated by assembling many photovoltaic cells. When the irradiations of sun strike on the surface of the solar PV system, it is converted into electricity. All these irradiations do not convert into electricity as some part of these irradiations are transformed into heat, which causes to increase the temperature of the solar panel. This phenomenon becomes more prominent in summer. It is observed that above Standard Temperature Conditions (STC), the efficiency of the photovoltaic system decreases with the increase of temperature. Hence, temperature and illumination have a strong impact on photovoltaic systems output power.

The standard test conditions (STC) have Air Mass (solar spectrum irradiance) of 1.5, illumination of 1000 W/m^2 and 25 °C temperature.

Performance of Photovoltaic system is explained by its efficiency and it is the utmost desire of researchers to get maximum power from these photovoltaic panels. The ratio of generated output power to the input solar irradiation is called efficiency (η) and it can be described as [3]

$$\eta = \frac{Voc * Isc * FF}{Pin} \tag{1.1}$$

As we can see from this equation that the efficiency of Photovoltaic Systems depends upon output parameters like open circuit voltage, short circuit current and fill factor.

For open circuit voltage, we can write it as [3]

$$\mathrm{Voc} = \frac{KT}{q} ln\left(\frac{\mathrm{Iph}}{Is}\right) + 1 \tag{1.2}$$

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

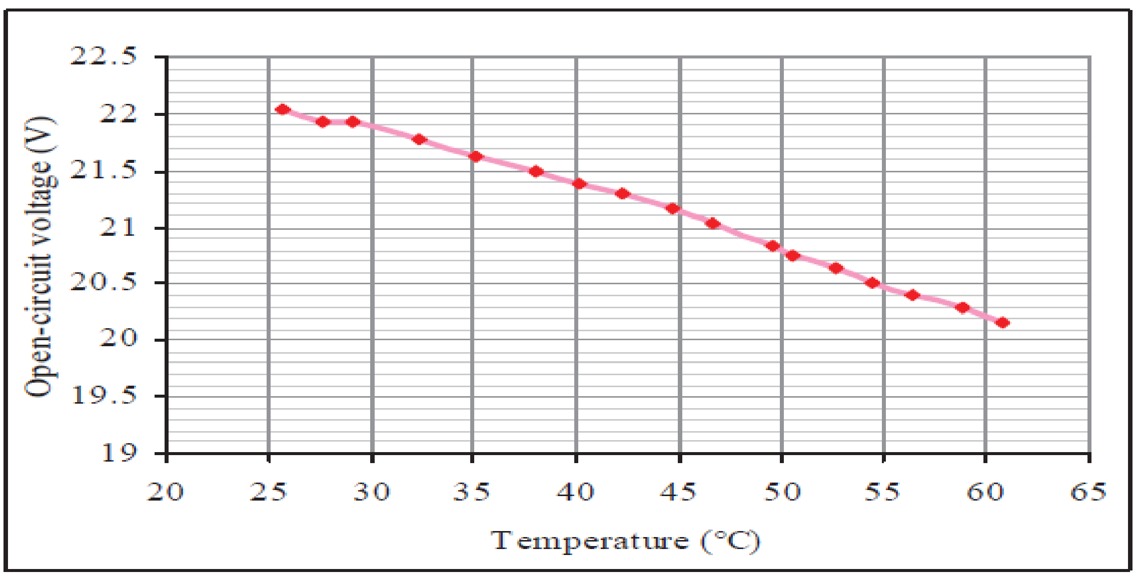

Fig 1.1: Impact of Temperature on Open Circuit Voltage [4]

For short circuit current, we can write it as [3]

$$\mathrm{Isc} = Is\left(exp\frac{\mathrm{q * Voc}}{KT} - 1\right) + \mathrm{Iph} \tag{1.3}$$

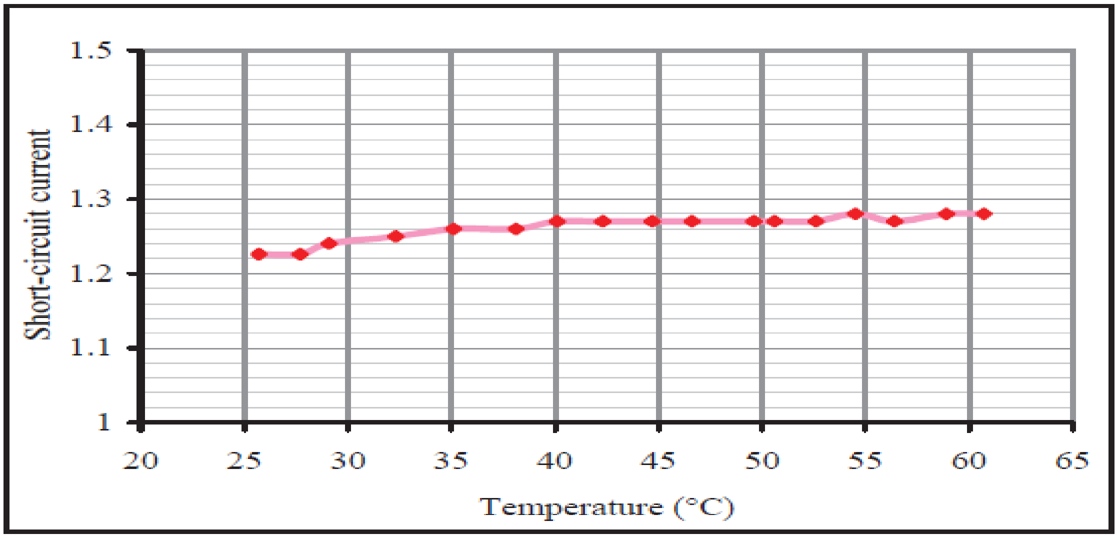

Fig 1.2: Impact of Temperature on Short Circuit Current [4]

For fill factor, we can write it as [3]

$$FF = \frac{Im * Vm}{Isc * Voc} \tag{1.4}$$

Where I_m represents maximum possible current while V_m represents maximum possible voltage.

Equation 1.2, 1.3, and 1.4 shows that output parameters of the photovoltaic system like open circuit voltage etc. depend on temperature while efficiency depends on these parameters. When temperature increases, it causes a reduction in the band gap of the solar cell due to which above mentioned parameters affects [4][5]. The most affected parameter by temperature is V_{OC} [6]. Therefore, the output power from the photovoltaic panel is linearly propositional to temperature & illumination [7].

It is observed that with the increase of temperature, solar PV cells output parameters like fill factor, open circuit voltage, output power and efficiency decreases [8]. This increase in temperature can reduce output power by 0.54%/ °C in case of the mono-crystalline module and 0.49% / °C in case of poly-crystalline modules [9]. For temperature over

25°C, the average drop in efficiency is approximately 0.45% for each degree increase in temperature [10]. The impact of increasing temperature on output power can be shown as in the figure below [4]

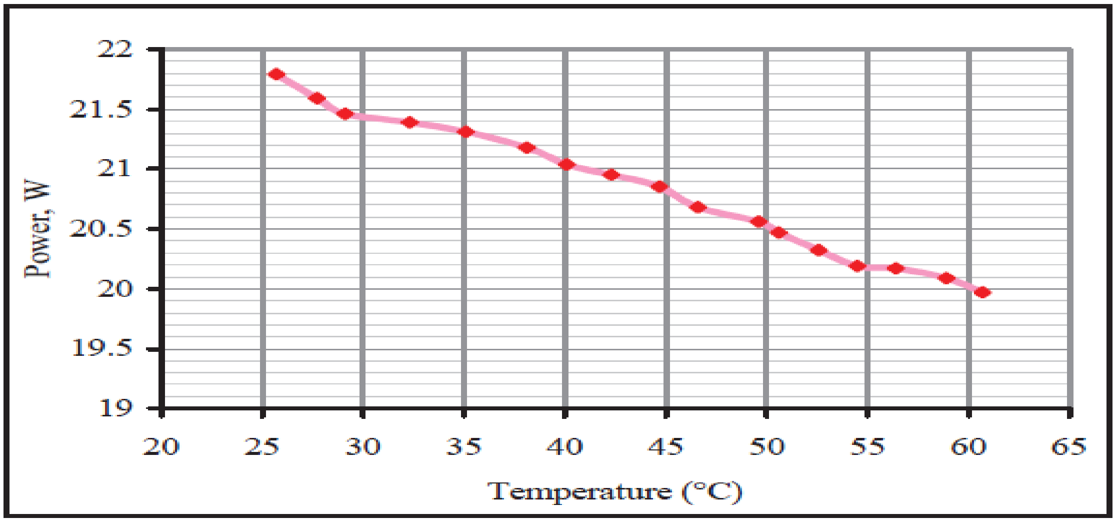

Fig 1.3: Impact of Temperature on output Power [4]

Similarly, the impact of changing illumination can be shown as in the figure below.

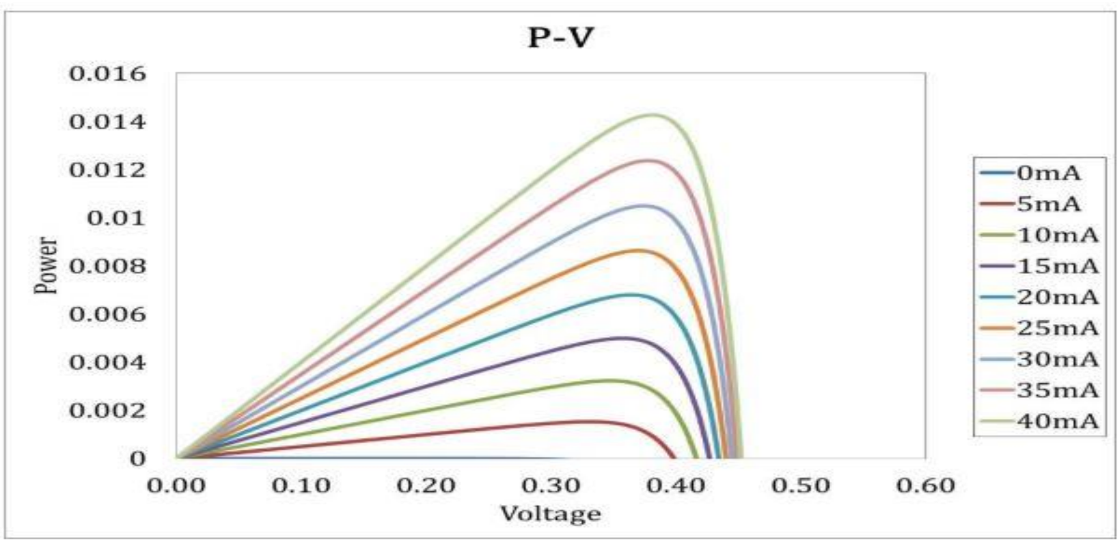

Fig 1.4: Impact of illumination on output Power-Voltage-Current [1]

Figure-1.4 shows that how the output power of PV cells changes with changing the level of illuminations. We can clearly see that with the increase in the amount of illumination, more will be heat produce, as not all irradiation converts to electricity and as result, there will be more temperature around the solar panel. Hence, the performance of solar photovoltaic cell decreases when the temperature is increased. Therefore, there is a strong need to find and maintain working of the solar photovoltaic system at the maximum power point by keeping temperature and solar illuminations in optimal conditions to get maximum output power.

The maximum output power of PV photovoltaic can be calculated as

$$Pmax = Voc * Isc * FF \tag{1.5}$$

1.5 Significance of the Problem

Photovoltaic systems have two main problems

- The efficiency of the Photovoltaic panel is low because it does not operate at its maximum power point [7].
- The efficiency of PV systems decreases as the temperature increases [1] - [15].

The photovoltaic panel has non-linear V-I characteristics with the unique point where output power is maximum. This point is called the maximum power point. Output power from solar panel varies with illuminations and temperature [7]. If the values temperature and solar illumination changes, output parameters of the photovoltaic system also change. Therefore, temperature and illumination have a strong impact on photovoltaic (PV) systems output power, which should be focused while modeling the photovoltaic system [1] - [10].

With the change in ambient temperature and illumination levels, operating temperature of the cell also changes which results in a new output voltage and a new value of photocurrent. The operating temperature of the solar cell varies as a function of ambient temperature and solar illumination. The best model should be designed in such a way that it focuses to boost up the annual power production by investigating the combined effect of temperature and illumination. [3].

1.6 The contribution of Solution to Field

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

It will find and maintain working of Solar photovoltaic system at the maximum power point to improve overall efficiency by keeping temperature and solar illuminations in optimal conditions to get maximum output power and this will be done by purposing new tracking solution to harvest and utilize solar irradiation as much as possible to increase the system efficiency and boost up the output power. This work will

- Improve the efficiency of the solar photovoltaic system
- Reduce energy/power losses due to excess temperature
- Minimizes the overall system cost
- Minimizes the size required for solar PV panels.

1.7 Literature Review

Energy is a basic need of human being from the very first day. Peoples use this energy to bring easiness in life and these energy forms can be converted from one form to another form. There are mainly two types of energy resources. One is called conventional energy resource while other is called non-conventional energy resource. Mostly, conventional energy resources like oil, gas, etc. fulfill energy needs but with the passage of time, these resources are being depleted. Moreover, these resources cause emission of dangerous gases while burning and due to which ecosystem of this universe disturbs. Therefore, it is the utmost need of time that such resources must be used that are not depleting with time and it is supporting the eco system of this universe as well.

The solution to this problem can be fulfilled by using renewable energy resources like solar, wind etc. This renewable energy is a far better option comparing with conventional energy in many ways like reliability, cost, pollution and the most important that these resources will not deplete with the passage of time. The mostly focused renewable energy source to fulfill the need of energy for future is solar photovoltaic technology as the sun is most reliable and renewable energy source because it will be available until Day of Judgment.

Solar Energy is an important energy resource due to its easy availability, cheapness, and cleanness. In these days, solar energy is getting more attention due to its technology that is developing rapidly, it has a strong capacity to meet energy demands of modern developing society, and it can be used for various purposes such as domestic & industrial water heating, drying of products, production of power and so on.

Solar energy may be harnessed by two ways from solar irradiations; one is called a thermal system, which converts solar irradiation into thermal energy to heat working fluid while the second type is a photovoltaic system.

In a photovoltaic system, solar irradiations may be converted to electricity directly by following photovoltaic Method. A photovoltaic cell is made from semiconductor materials like silicon, Gallium Arsenide, Cadmium telluride etc.

The photovoltaic panel is incorporated by assembling these photovoltaic cells. Each PV cell generates approximately about 2 watts with 0.6 V voltages. These solar cells are connected in serial-parallel combination to produce required voltage, current, and power.

When the irradiations of sun strike on the surface of the solar PV system, it is converted into electricity. All these irradiations do not convert into electricity as some part of these irradiations are transformed into heat, which causes to increase the temperature of the solar panel. This phenomenon becomes more prominent in summer. It is observed that above Standard Temperature Conditions (STC), the efficiency of the photovoltaic system decreases with the increase of temperature. Hence, temperature and illumination have a strong impact on photovoltaic systems output power.

It is observed that with the increase of temperature, solar photovoltaic cell parameters like open fill factor, circuit voltage, output power and efficiency decreases [8]. This increase in temperature can reduce output power by 0.54%/ °C in case of the mono-crystalline module and 0.49% / °C in case of poly-crystalline modules [9]. For temperature over 25°C, average reeducation inefficiency is approximately 0.45% for each degree [10].

Solar cells dependence on temperature and illumination and its performance has been thoroughly studied by many authors [11] - [15]. Many manufactures also confirmed that efficiency of PV systems decreases with the increase of temperature of PV cell [16] - [19]. Solar photovoltaics cells are sensitive to temperature like all other semiconductor materials. The band gap of a semiconductor materials decreases with increases in temperature, thereby affecting the solar PV cell output parameters. The most affected parameter by temperature is V_{OC} [6].

Production of electrical power and radiant power density depends on PV module temperature. Some percentage of illumination is converted directly to electricity while dispersing the rest part as heat, which results in a higher module's temperature.

It is the utmost aim of researchers to study the parameters that affect the performance of PV cells and wish to design and develop in such a way that it is most useful. It has been concluded that temperature and illumination have a great impact on PV cell's performance.

Extensive researches have been proposed to assess the module temperature for effective results. However, researchers are unable to identify and develop models that can find and assess the effects of each wavelength of the spectral irradiance on module temperature.

It is observed that the efficiency of the Photovoltaic panel is low because it does not operate at its maximum power point [7]. Moreover, Efficiency of Photovoltaic systems decreases as the temperature increases [1] - [15]. When solar illuminations and ambient temperature levels change, the operating temperature of cells also changes that result in a new value of photocurrent and output voltage. The operating temperature of the solar cell varies as a function of ambient temperature and solar illumination. The best model should be designed in such a way that it focuses to boost up the annual power production by investigating the combined effect of temperature and illumination [3].

In this thesis, modeling of a single photovoltaic cell incorporating its working equations and considering cell temperature and illumination as the combined effect is carried out.

The main objective of this work is to find and maintain the operation of the photovoltaic system at the Maximum Power Point to improve overall efficiency by keeping temperature and solar illuminations in optimal conditions to get maximum output power.

This is done by purposing new tracking solution to harvest and utilize solar irradiation as much as possible to increase the system efficiency and boost up the output power. Moreover, a detailed discussion is also done to select a suitable type of solar panel to get more power to increase efficiency at the same temperature and illumination. Karachi (Pakistan) had been chosen to be the location of our study due to the availability of global weather data for a whole year easily. These simulations held using Rhino/Grasshopper with the 3D environment. Rhinoceros is a state-of-the-art computer-aided design (CAD) software developed by Robert McNeel & Associates in 1980, which can be used to generate complex geometries and 3D models. Similarly, Grasshopper is also a state-of-the-art programming language that is developed by David Rutten at Robert McNeel & Associates and it runs within the Rhinoceros or simply Rhino 3D. Advance uses of Grasshopper include parametric modeling for architecture and fabrication and environmentally friendly Building Energy design. On another hand, Grasshopper also provides a visual programming language with a wide range of add-ons, such as Ladybug, Honeybee, EnergyPlus, Irradiation, and many other useful add-ons that enhance the simulation performance. This work opens the gate widely in front of different trends and future study in which the 3D tools and weather data is utilized to study the solar electrical system which is the main area of novelty.

1.8 Thesis Summary

This thesis/ work is distributed in the following chapters. Chapter 1 is an introduction. Chapter 2 is Explaining the Modeling of a PV cell. 3rd Chapter is discussing the Proposed Model. 4th Chapter is about Working of Proposed Model. Chapter 5 is about Results & Discussion. Finally, the Conclusion and Future Work are part of the 6th chapter.

CHAPTER 2

PHOTOVOLTAIC CELL

2.1 Modeling of Photovoltaic Cell

Photovoltaic (PV) Cells use solar illumination to convert it directly to electricity. Alexander Edward Becquerel discovered solar Photovoltaic (SPV) technology in 1839. He discovered photovoltaic effect when he exposes conductive solution to light through electrode. With the passage of time, many researchers also worked on photovoltaic effect to make use of it in many other phenomena. Some of the scientists that contributed to the development of this effect were Edward Weston, Charles Fritts, Nikola Tesla, and Albert Einstein, who was awarded a noble prize for his work on Photovoltaic Effect in 1921 but he received this award in 1922.

In a photovoltaic system, solar irradiations may be converted to electricity directly by following photovoltaic phenomena. When the irradiations of sun strike on the surface of the solar PV system, it is converted into electricity.

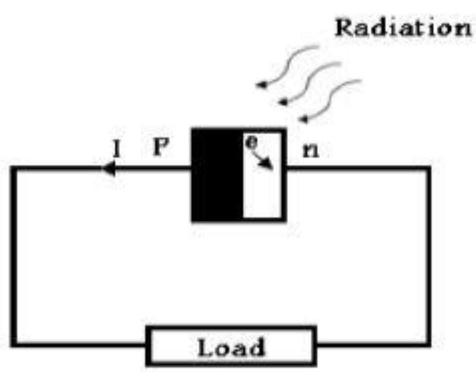

Fig 2.1: Photocurrent Generation Principal

Photovoltaic Cells are actually PN Junctions that are fabricated with a thin layer of semiconductor materials like silicon, Gallium Arsenide, Cadmium telluride etc. Figure

2.1 shows the photocurrent generation principal of PV cells. When solar irradiation strikes on the surface of this semiconductor surface, it frees electrons from N-type layer, which travels towards P-type layer resulting flow of current.

The photovoltaic panel is incorporated by assembling these photovoltaic cells. The first practical photovoltaic cell was manufactured in 1954 and was principally used to provide electric power to the orbital satellites.

Each PV cell generates approximately about 2 watts with 0.5V to 0.8V voltage. These solar cells are connected in serial-parallel combination to produce required voltage, current, and power. To get higher voltage, these cells are connected in series combination and if we need a higher amount of current, then these cells are connected in parallel combination.

We can draw an equivalent circuit to understand the concept of the photovoltaic cell [20]

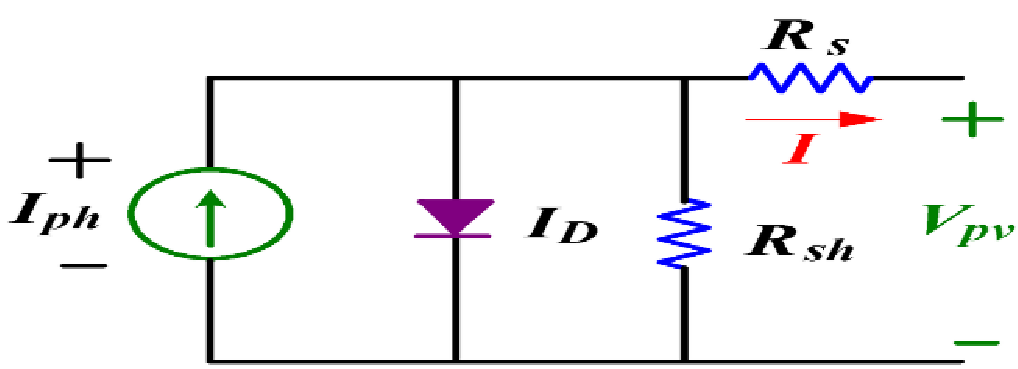

Fig 2.2: Equivalent circuit of Photovoltaic Cell [1]

From this equivalent circuit of the photovoltaic cell, we can write mathematically

$$Iph = Id + Ish + Ipv \tag{2.1}$$

Where Rs = Series Resistance, Rsh = Shunt Resistance, Id = Current of Diode, Iph= Photon Current, Ish = Current through Shunt Resistance, Vpv = Output Voltage, Ipv = Output Current

2.2 Characteristics of Solar Cell

Characteristics of the solar photovoltaic cell can be described by current-voltage (I-V) and power-voltage (P-V) curves. PV systems show non-linear current-voltage (I-V) and power-voltage (P-V) characteristics, which vary with ambient, weather conditions.

Current-Voltage (I-V) and Power-Voltage (P-V) characteristics can be shown as the figure below.

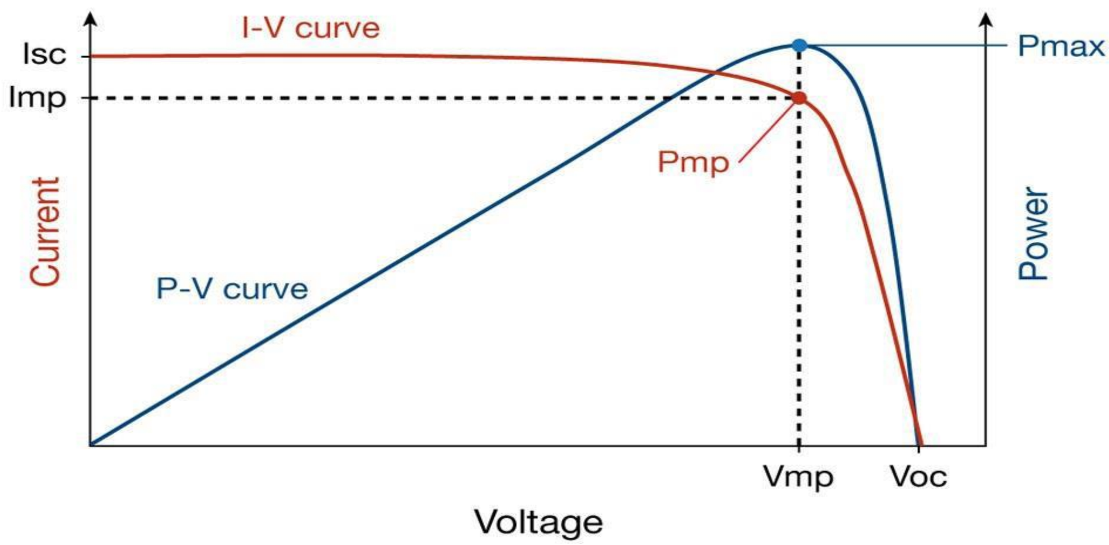

Fig 2.3: P-V & I-V Curves of Photovoltaic Cell [21]

As it is clear from figure 2.3 that parameters related to solar cell characteristics are short circuit current, open circuit voltage, maximum power point and fill factor.

Solar cells main parameters related to solar cell characteristics can be explained as follow.

A. *Open Circuit Voltage (V_{OC})*

V_{OC} is the voltages that are produced across the internal diode when a total generated photocurrent flows through this diode. Mathematically, it can be explained as [3]

$$Voc = \frac{KT}{q} ln\left(\frac{\text{Iph}}{Is}\right) + 1 \tag{2.2}$$

Where K represents Boltzmann Constant, q represents Electronic Charge, T represents Temperature, I_{ph} is Photocurrent and I_S represents Diode Saturation Current.

B. Short Circuit Current (I_{SC})

Short circuit current can be explained mathematically as follow [3]

$$\mathrm{Isc} = Is\left(exp\frac{\mathrm{q} * \mathrm{Voc}}{KT} - 1\right) + \mathrm{Iph} \tag{2.3}$$

C. Maximum Power Point (MPP)

A point on these P-V and I-V curves where Photovoltaic Cell produces maximum power is called Maximum Power Point and is denoted with $Pmax$.

$$Pmax = Vmpp * Impp \tag{2.4}$$

Where *Pmax is* maximum power, *Vmpp* represents maximum power point voltage and Impp represents Maximum Power Point current.

D. Fill Factor

It is the ratio of peak power to the product of V_{OC} and I_{SC}. Mathematically, it can be explained as [3]

$$\mathrm{F.F} = \frac{Im * Vm}{Isc * Voc} \tag{2.5}$$

Performance of Photovoltaic system is explained by its efficiency and it is desired to get maximum power from photovoltaic panels. The ratio of generated output power to the input solar irradiation is called efficiency (η) and it can be described as [3]

$$\eta = \frac{Voc * Isc * FF}{Pin} \tag{2.6}$$

Equation 2.2, 2.3 and 2.5 show that open circuit voltage, short circuit current and fill factor depends on cell temperature while efficiency depends on these parameters. So, PV performance should be observed while keeping in view of weather conditions.

2.3 Performance of PV Cell with changing Temperature

It is observed that with the increase in temperature, solar photovoltaic cell parameters like open circuit voltage fill factor, output power and efficiency decreases [8] as it is explained in Equation 2.2, 2.3 and 2.5. This increase in temperature can reduce output power by 0.54%/ °C in case of the mono-crystalline module and 0.49% / °C in case of poly-crystalline modules [9]. For temperature over 25°C, average reeducation inefficiency is approximately 0.45% for each degree [10].

This effect of changing temperature over I-V curve of the photovoltaic cell can be shown as follow.

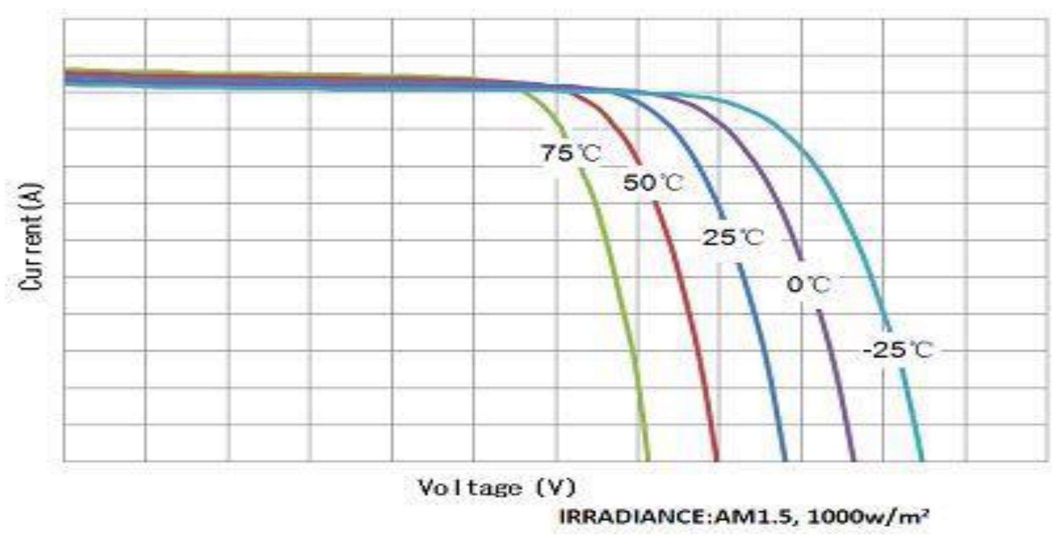

Fig 2.4: I-V curves of photovoltaic cell at different temperatures [22]

Figure 2.4 shows that at constant illumination when the temperature of PV cell is changed from -25ºC to 75 ºC the output value of the current of voltage also changes. It can be easily concluded that with the increase in temperature, short circuit current slightly increases while open circuit voltage decreases as shown in figure 2.4.

Similarly, we can see the effect of changing temperature over the P-V curve of a photovoltaic cell as follow

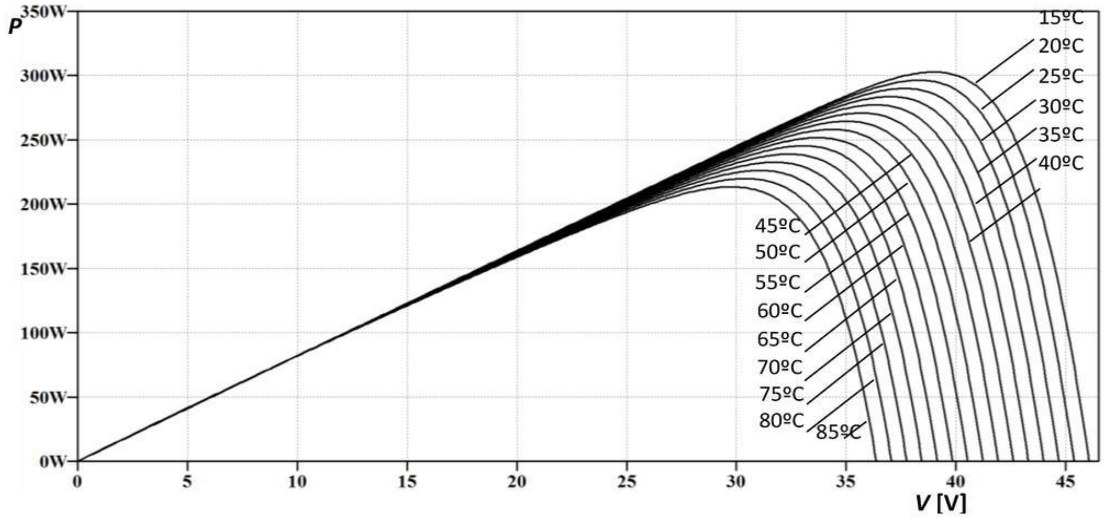

Fig 2.5: P-V curves of the solar photovoltaic cell at different temperatures [22]

Figure 2.5 shows that at constant illumination when the temperature of the PV cell is changed from 15^{o}C to 85 ^{o}C output value of power decreases. It means that temperature is inversely propositional to the photovoltaic cell output power. When the temperature increases, output power decreases.

2.4 Performance of PV Cell with changing Illumination

It is observed that output power is directly propositional to solar illumination. When the number of illumination increases, output voltage and current also increase and due to to which output power also increase and vice versa. Maximum power point (MPP) of the solar point also changes directly propositional to solar illumination.

This effect of changing illumination over the I-V curve of the photovoltaic cell can be shown as follow.

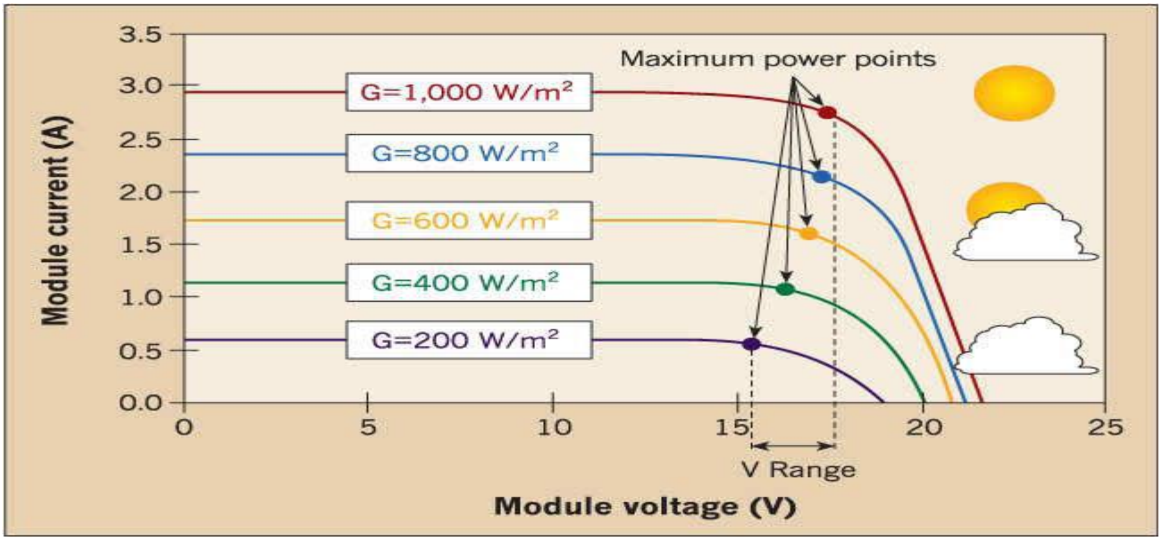

Fig 2.6: I-V curve of the solar photovoltaic cell at different illuminations [23]

Figure 2.6 explains that with the increase in illumination, output voltage and current also increase which produce higher output power. It can be shown as in the figure below

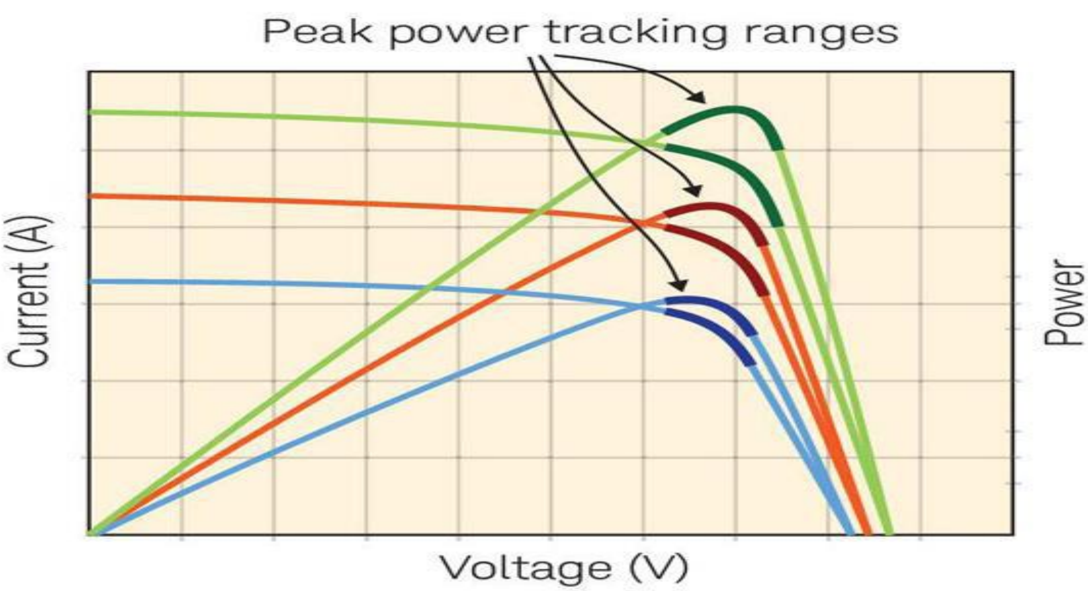

Fig 2.7: P-I-V curves of the solar photovoltaic cell for different illuminations [24]

When the irradiations of sun strike on the surface of the solar PV system, it is converted into electricity. All these irradiations do not convert into electricity as some part of these irradiations are transformed into heat, which causes to increase the temperature of the solar panel. This phenomenon becomes more prominent in summer.

CHAPTER 3

PROPOSED MODEL

3.1 Introduction

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

Rhinoceros is a state of the art computer-aided design (CAD) software developed by Robert McNeel & Associates in 1980, which can be used to generate complex geometries and 3D models. Similarly, Grasshopper is also a state of the art programming language that is developed by David Rutten at Robert McNeel & Associates and it runs within the Rhinoceros or simply Rhino 3D. Advance uses of Grasshopper include parametric modeling for architecture and fabrication and environmental friendly Building Energy design. On another hand, Grasshopper also provides a visual programming language with a wide range of add-ons, such as Ladybug, Honeybee, EnergyPlus, Irradiation, and many other useful add-ons that enhance the simulation performance.

These simulations held using Rhino/Grasshopper, in which a building/Geometry is designed to have a PV system mounted on its roof to study the solar path, temperature, wind rose and amount of irradiation encountered by the building on annual basis. The geometry built with a property to be tuned in width and length to meet the desired area of several suggestions.

This weather study considers the conditions in Karachi Pakistan based on global actual weather data. Based on the above data, the building encounters a known amount of irradiation and temperature annually. Whole system, geometry, and PV system was constructed with the aid of the Rhino parametric plugin, Grasshopper.

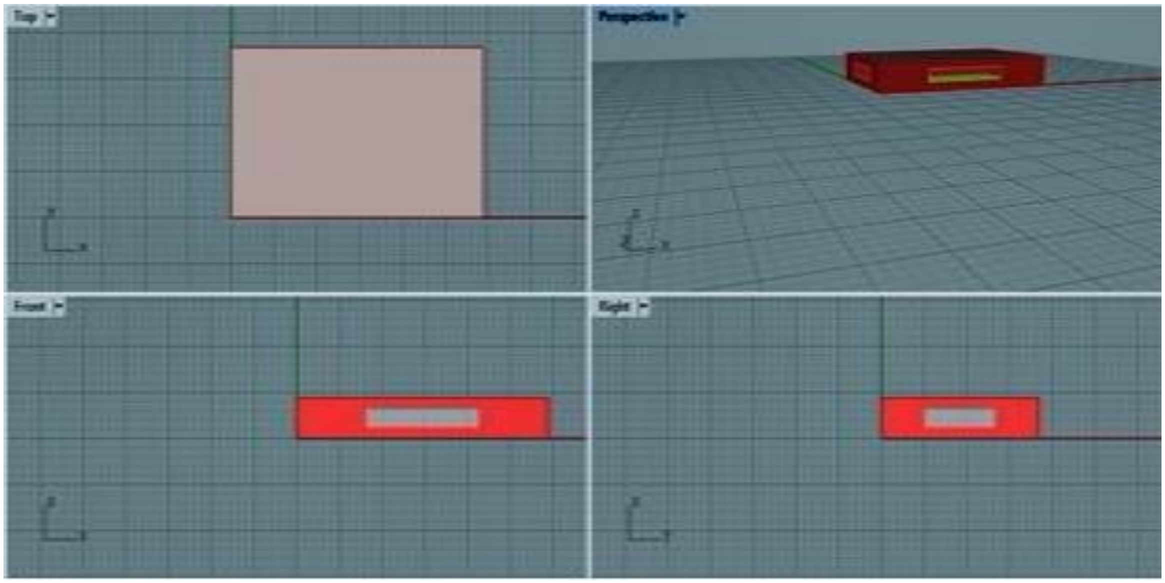

Fig. 3.1: Top, Front, Right and Prospective view of Building Design using Rihno/Grasshopper

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

3.2 Layout of Proposed Model

The layout is the process of planning that how the design or project will be implemented showing in the form of different block diagrams. Therefore, the layout is very useful to understand the new models that how different component will be connected.

Similarly, we can make a layout of this proposed model that how different sections are connected with each other as shown in the figure below.

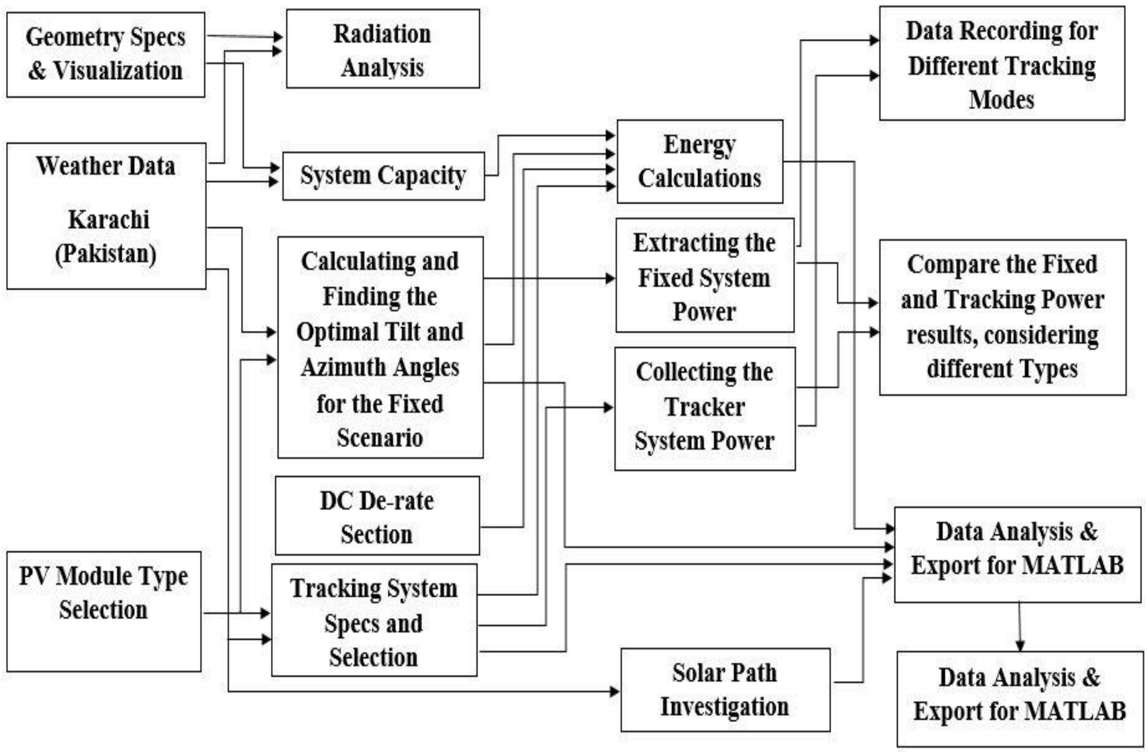

Fig 3.2: Layout of the Proposed Model

3.3 Modelling of Proposed Model

In this work, a 3D simulation environment is run and rendered for a PV system constructed on a specific geometry. Building/Geometry is designed to have a PV system mounted on its roof to study the solar path, temperature, wind rose and the amount of irradiation encountered by the building on annual basis. The geometry built with a property to be tuned in width and length to meet the desired area of several suggestions.

These simulations held using Rhinoceros /Grasshopper. Implementation of Proposed Model can be seen in fig 3.3.

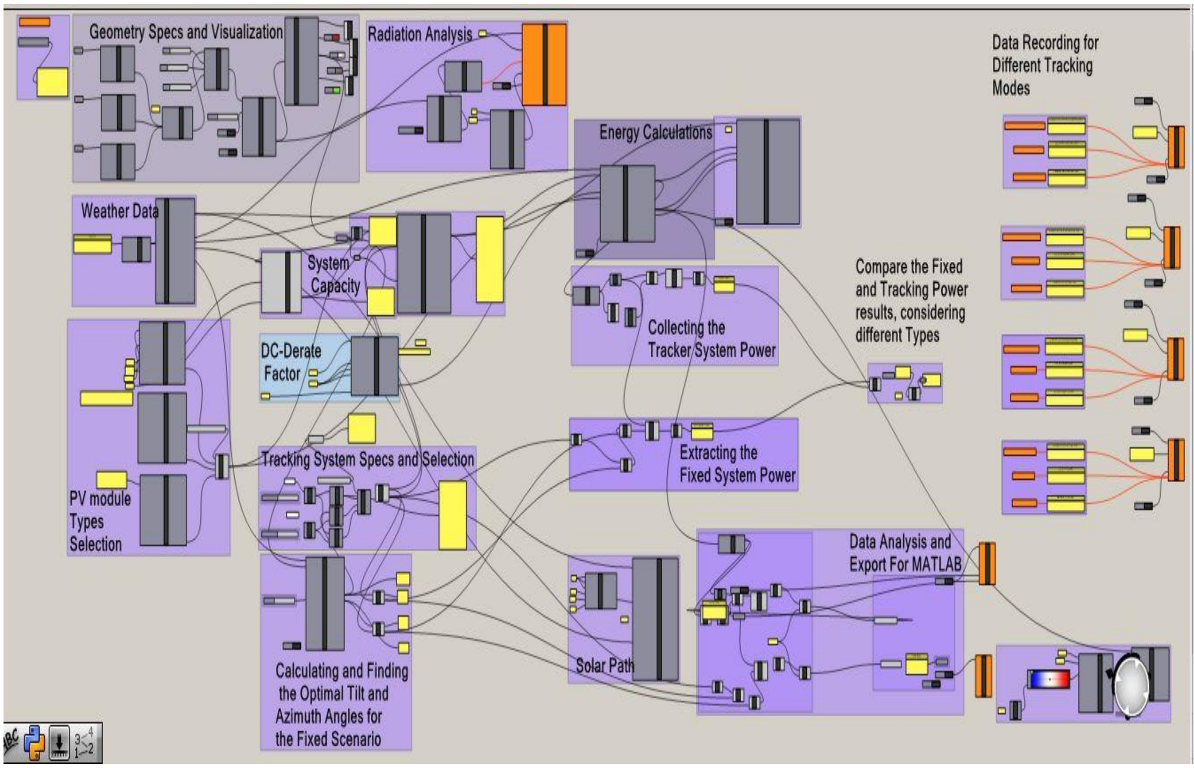

Fig 3.3: Implementation of Proposed Model in Rihno/Grasshopper

The important sections of this proposed model can be explained as follow.

A. The Geometry Section

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

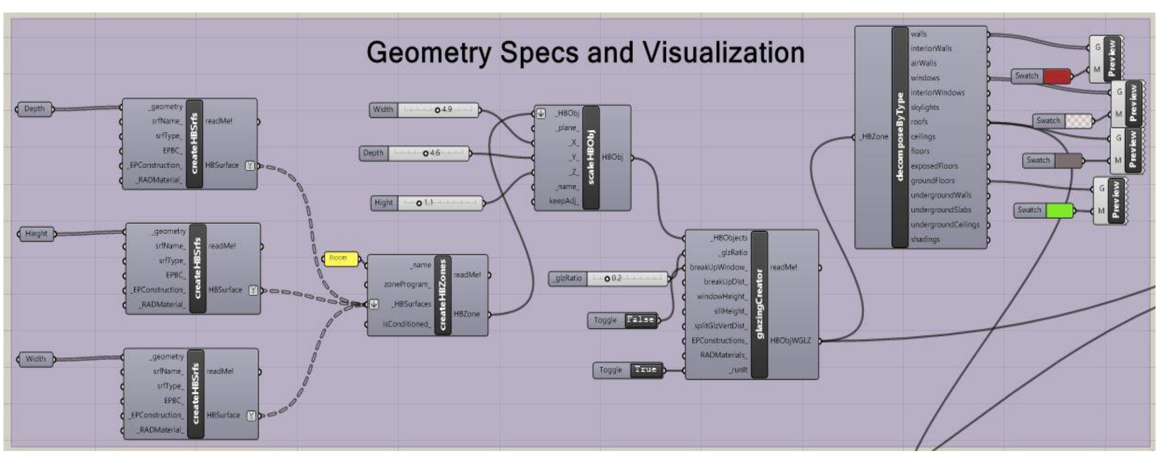

Fig 3.4: Geometry Specs and Visualization

B. Weather Data Section

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

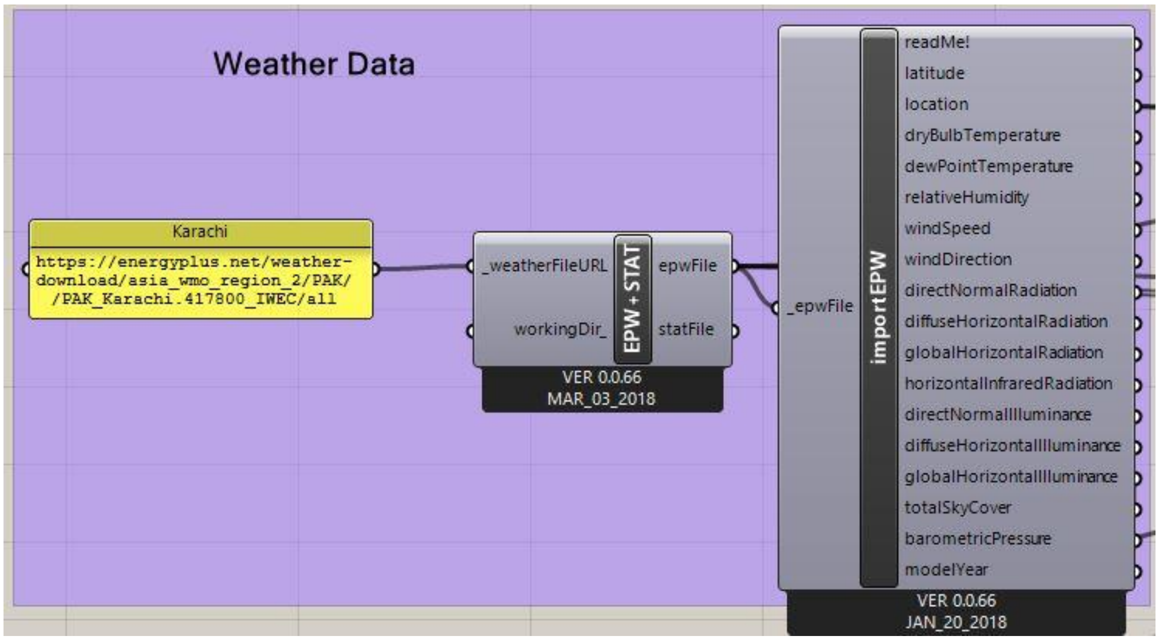

Fig 3.5: Weather Data

C. PV Module Selection

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

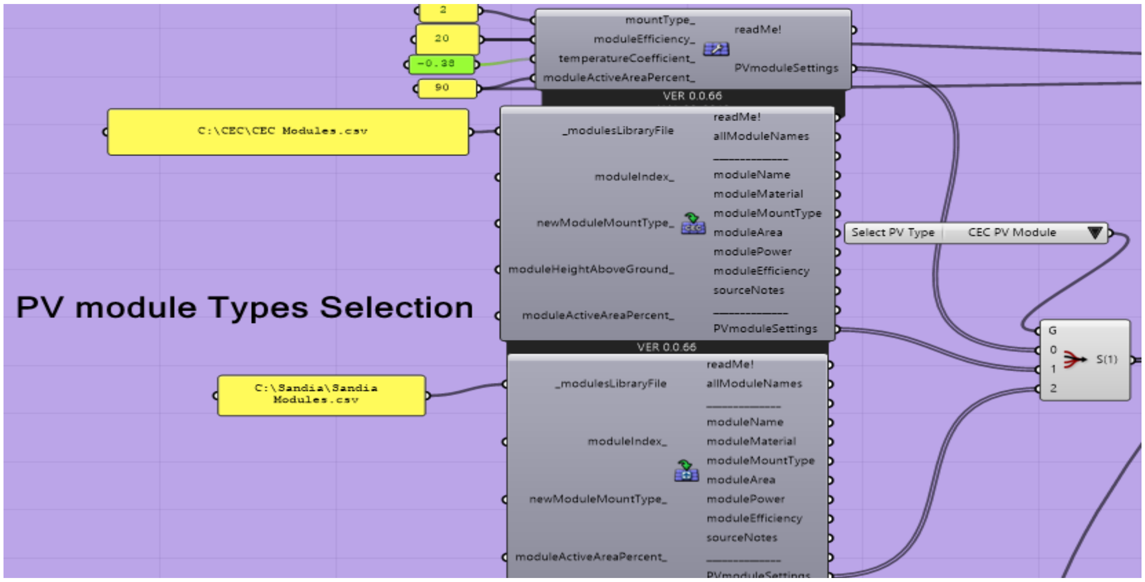

Fig 3.6: PV Module Selection

D. DC De-Rate Factor:

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

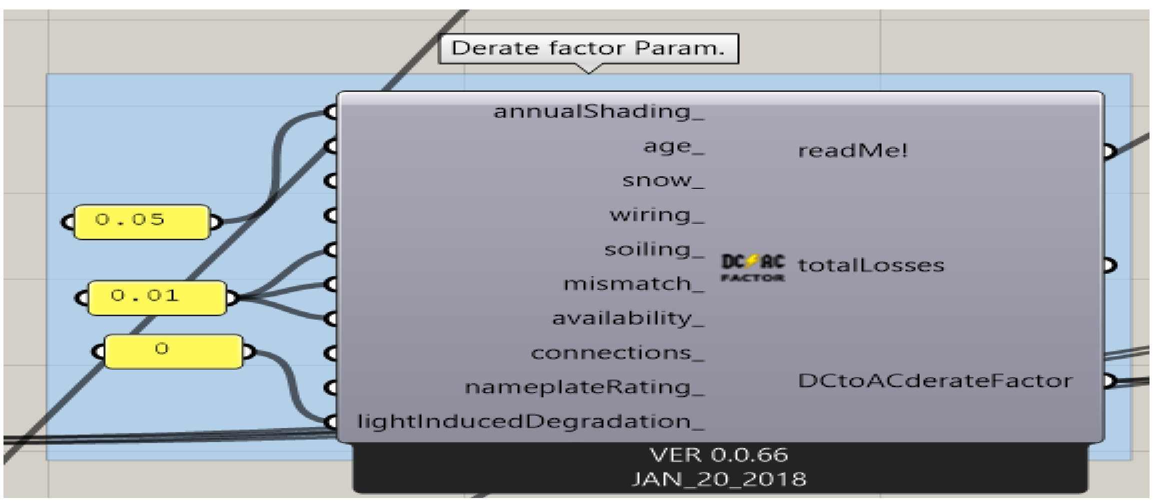

Fig 3.7: DC De-Rate Factor

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

This component calculates the optimal Tilt and Azimuth angles depending on the location data provided from the epw component. The sliders indicated a resolution of simulation. It is not preferred to have it more than 30 degrees, as it needs high computer resources and a very long time.

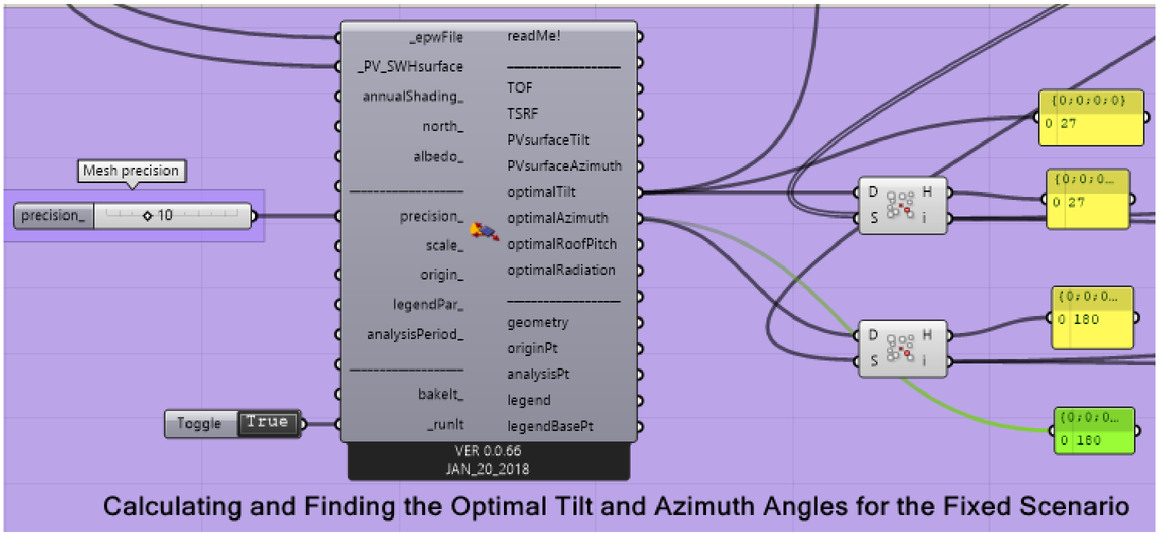

Fig 3.8: Calculating the Optimal Tilt and Azimuth Angles

F. Calculating the System Capacity

Depending on the area of the roof surface declared, the system size (capacity in KW) of the system is calculated using a small Python code in the python component and then fed to the other component that depends on this value. This model has a system capacity of 97.38 KW with an area of scaled Geometry is 540.96 m^2 as shown in the figure below which can be changed as desired.

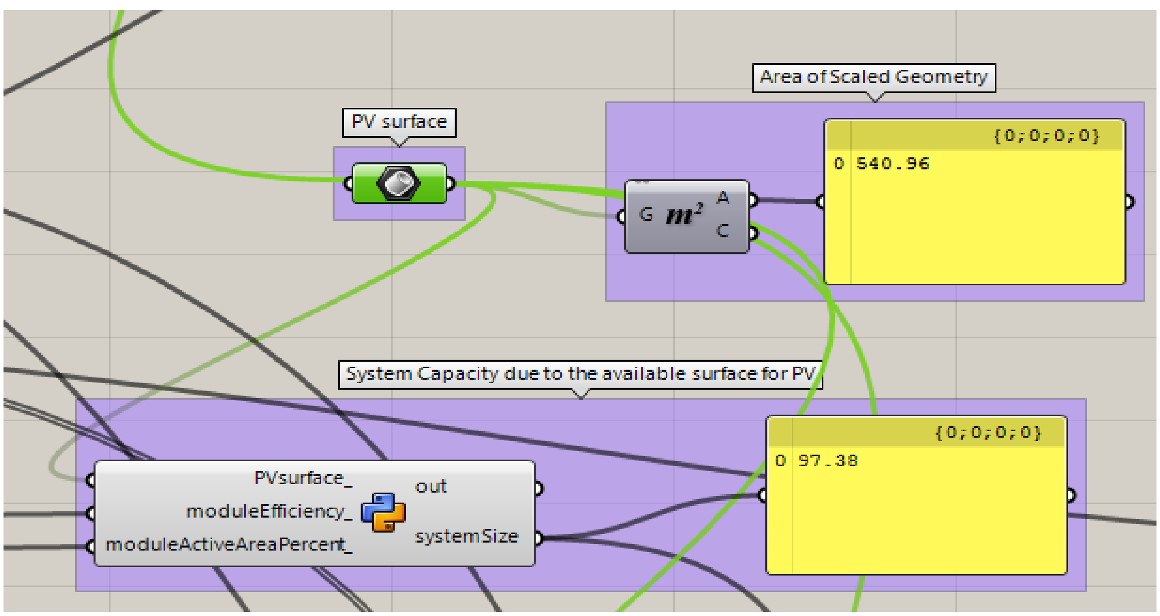

Fig 3.9: Calculating System Capacity

G. Tracking System Specs and Properties

This is a very important section, in which we can control tracking system modes in which PV cell can track the sun using: Horizontal Axis, Vertical Axis or Dual Axis. That means that there are two angles to vary Azimuth and Tilts angles.

The precision of the step size can be determined using the two sliders. It should be noted that the higher the slider numbers, the more time needed to process the output data.

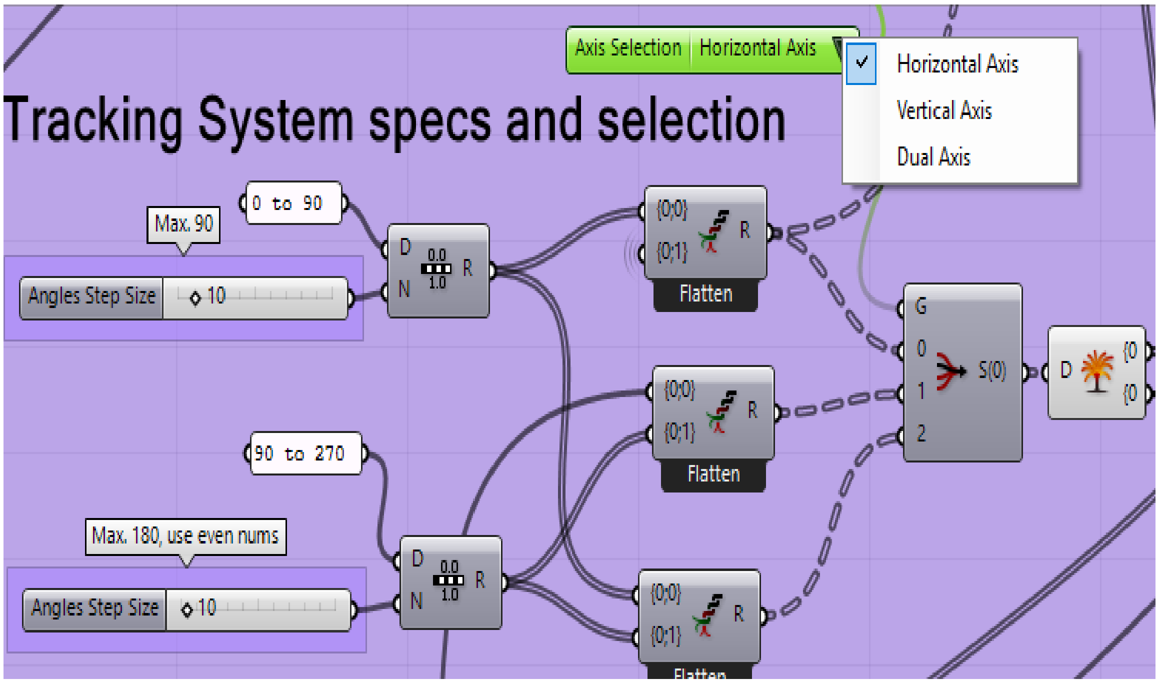

Fig 3.10: Tracking System Specs and Selection

H. Energy Calculations

This component calculates the core outputs of the PV system. From this component, we can have the power outputs of the fixed and tracking scenarios. In addition, we can have the irradiation and cell temperature outputs that can be used in the MATLAB file to generate the power and V-I curves.

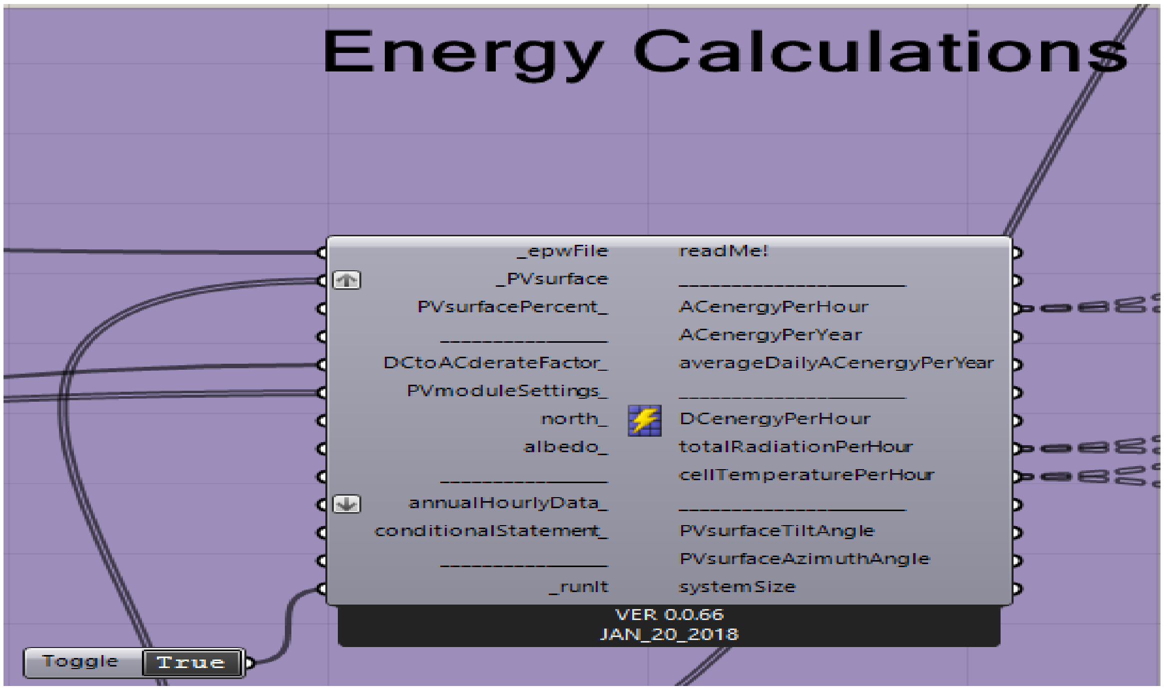

Fig 3.11: Energy Calculations

I. *Output Power for Different Modes*

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

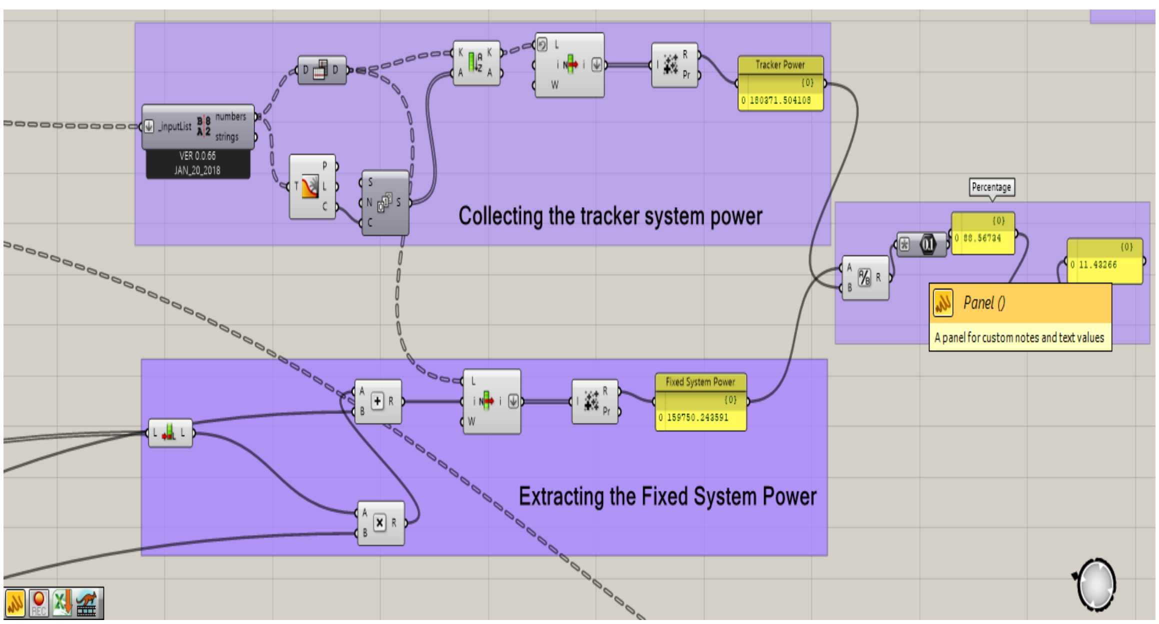

Fig 3.12: Output Power for Fixed and Tracking System

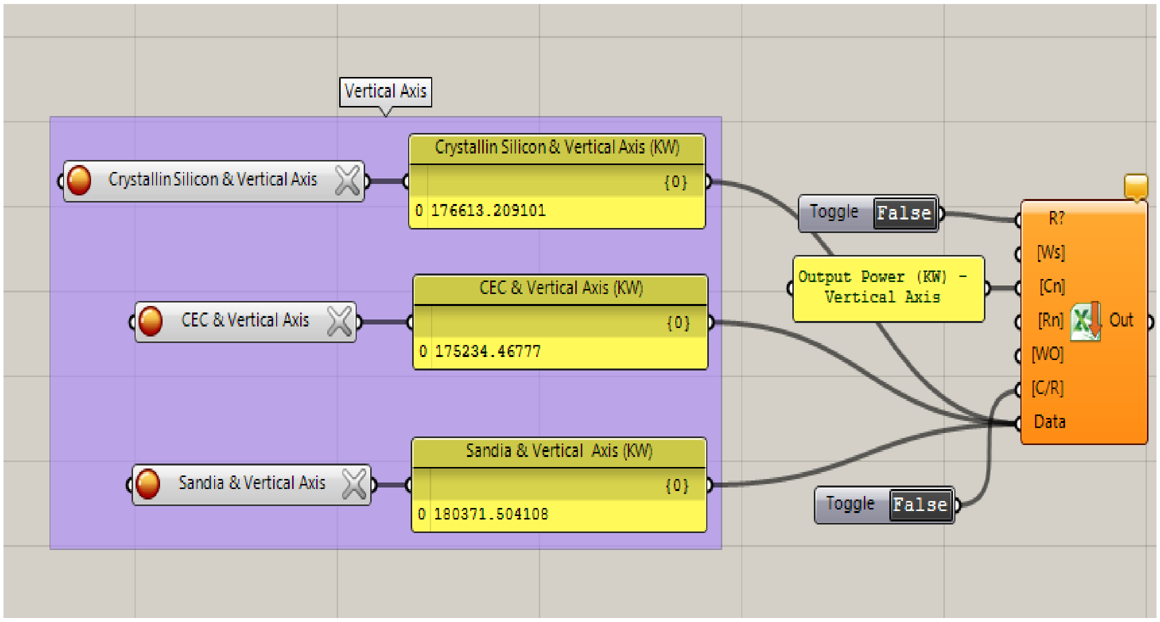

Fig 3.13: Output Power for Different Modes

J. Data Analysis for MATLAB

The following block gives us the ability to study and analyze different types of data. Such as irradiation and temperature. These data can be also exported to MATLAB to be studied through the PV cell module.

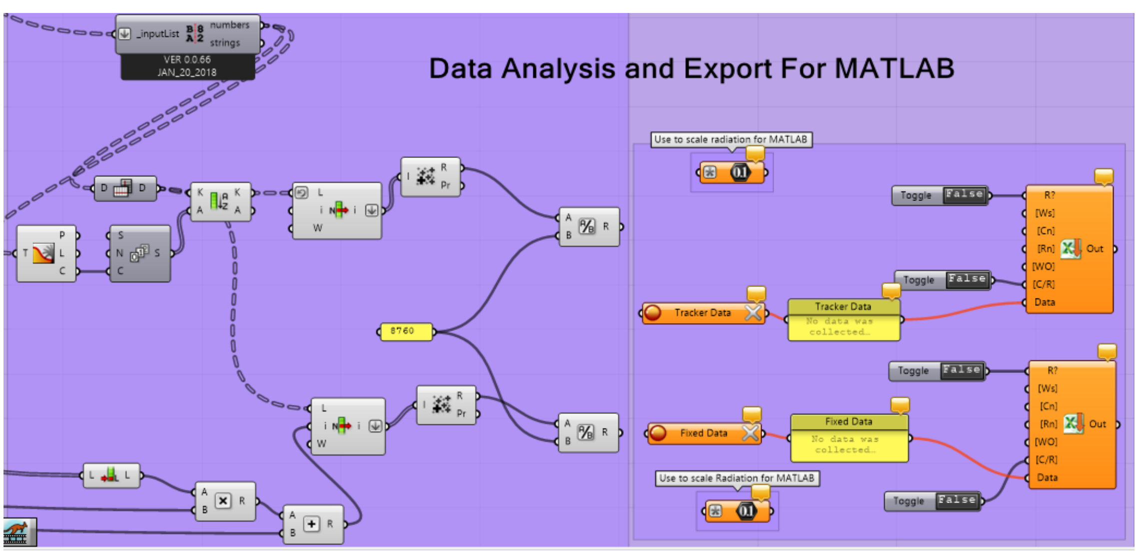

Fig 3.14: Data Analysis and Export for MATLAB

K. Solar Path Investigation

Using this component, we can analyze the sun position that throughout the year or even a specified period of the year. This useful when we want to know the exact position of the sun that achieves a kind of data. For example, we can specify the sun positions that achieve the amount of irradiation more than 800 W/m^2h in June.

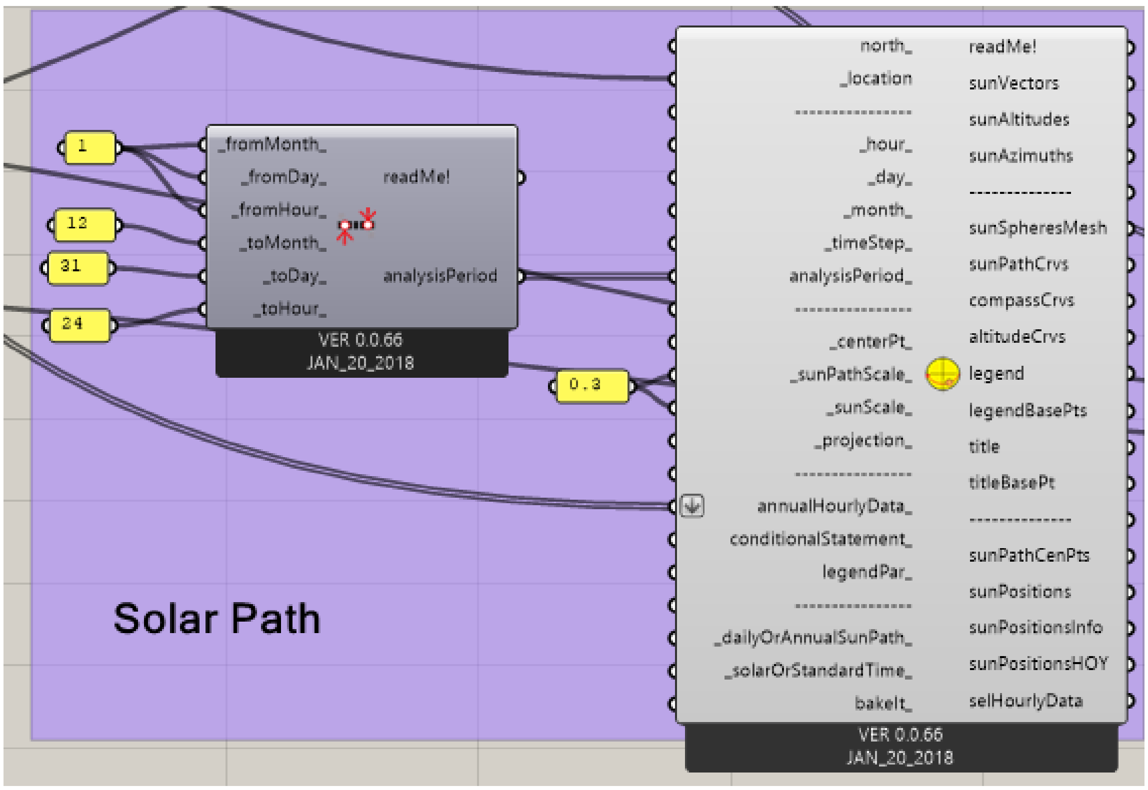

Fig 3.15: Solar Path Investigation

L. Visualization

This block is used to visualize any kind of data that we wish. We can visualize the irradiation, for example, as shown in the program. All we need is to right click and enable this component.

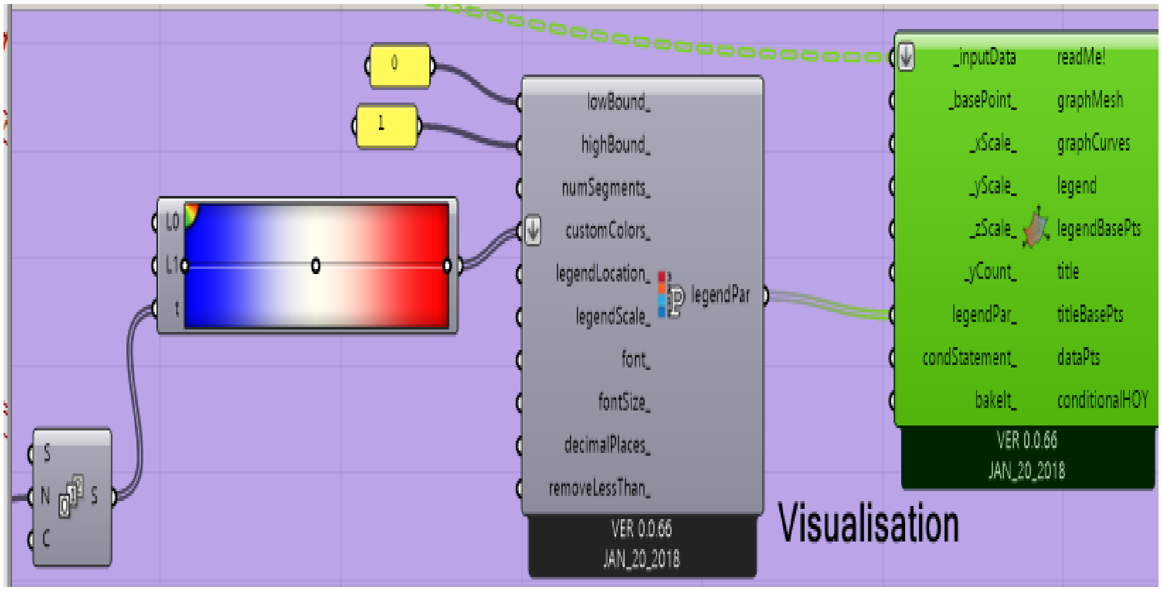

Fig 3.16: Visualization

M. Irradiation Analysis

This block can use for a different kind of irradiation analysis as per requirement/needs of the system.

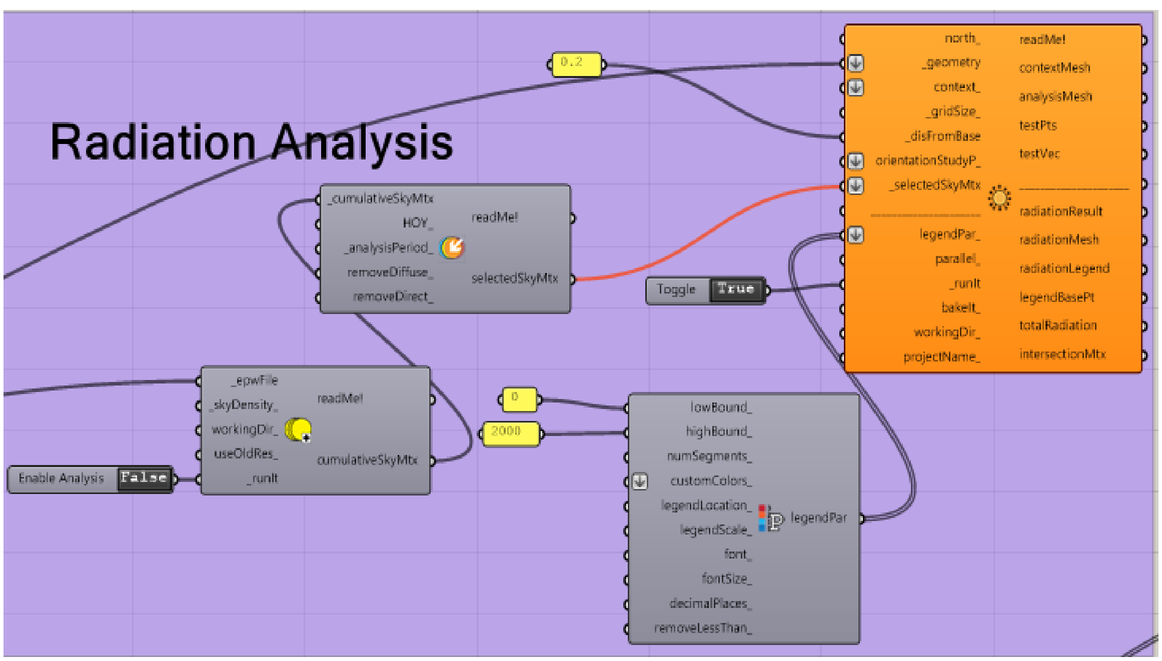

Fig 3.17: Irradiation Analysis

CHAPTER 4

WORKING OF PROPOSED MODEL

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

It is a unique property of Rhino/ Grasshopper that by giving weather file URL, all hourly weather data is imported to Model which can be further explained in figure 4.1 shown below.

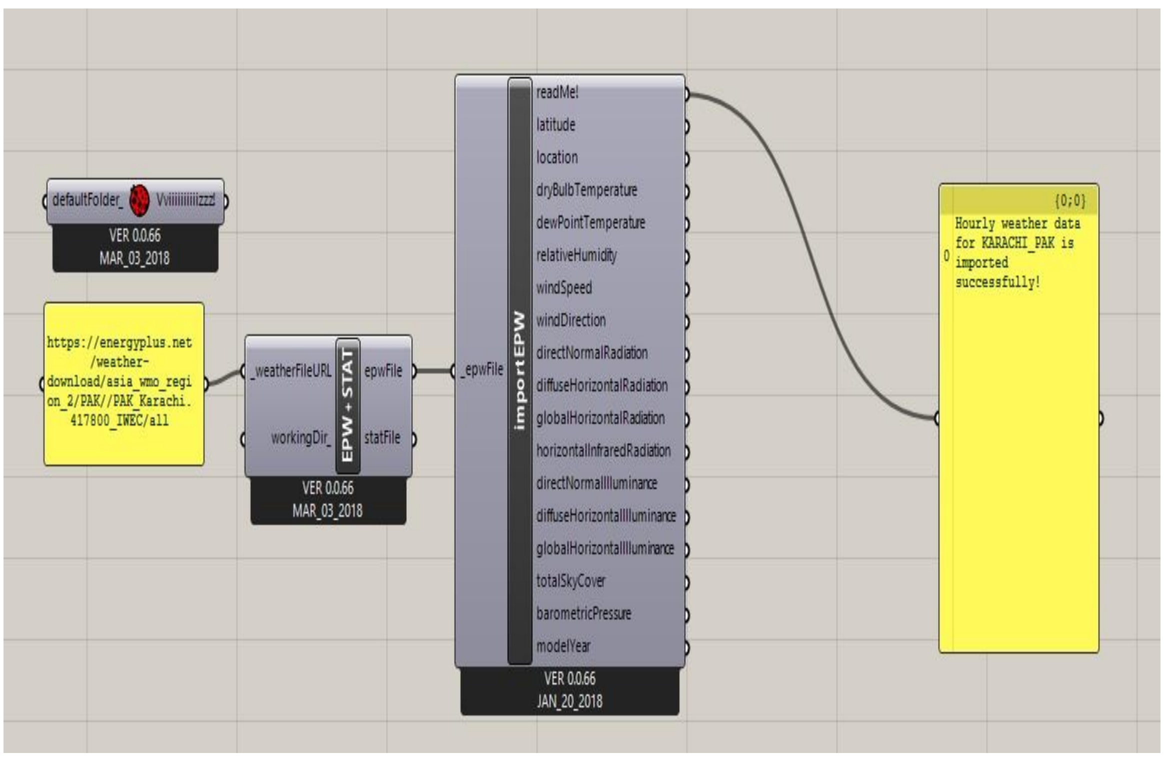

Fig. 4.1: Import of Weather Data to Proposed Model

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

Similarly, Location of Imported Weather Data using Rhino/Grasshopper can be seen as follow by giving weather file URL, which gives all kind of weather data for analysis.

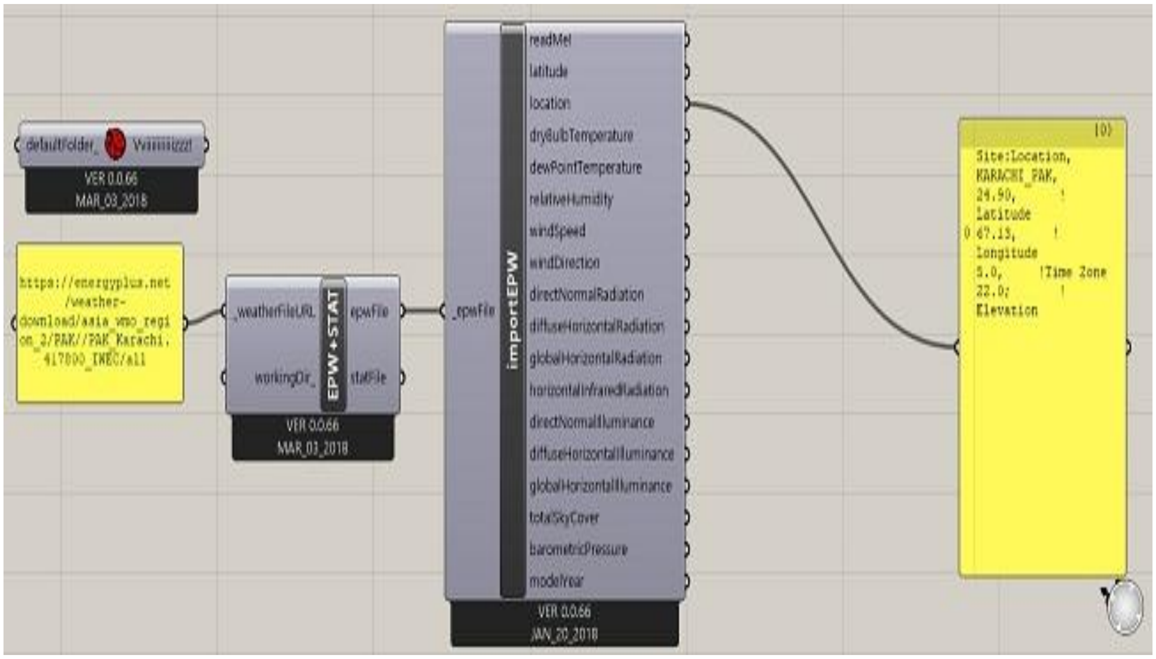

Fig. 4.2: Location of Imported Weather Data

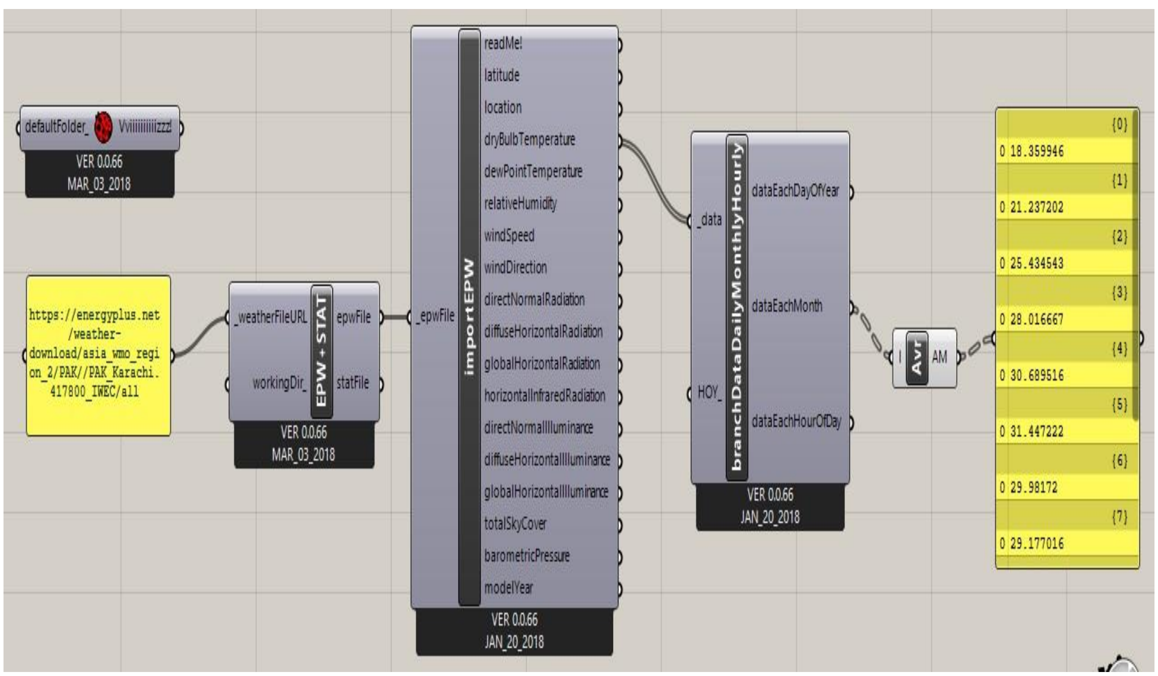

Fig. 4.3: Import of Monthly Dry Bulb Temperature

In fig.4.3, monthly dry bulb temperature can be seen through a display panel. This export data can be saved in excel form for further process by right clicking on display panel and using command “Stream Contents” as shown in the figure below.

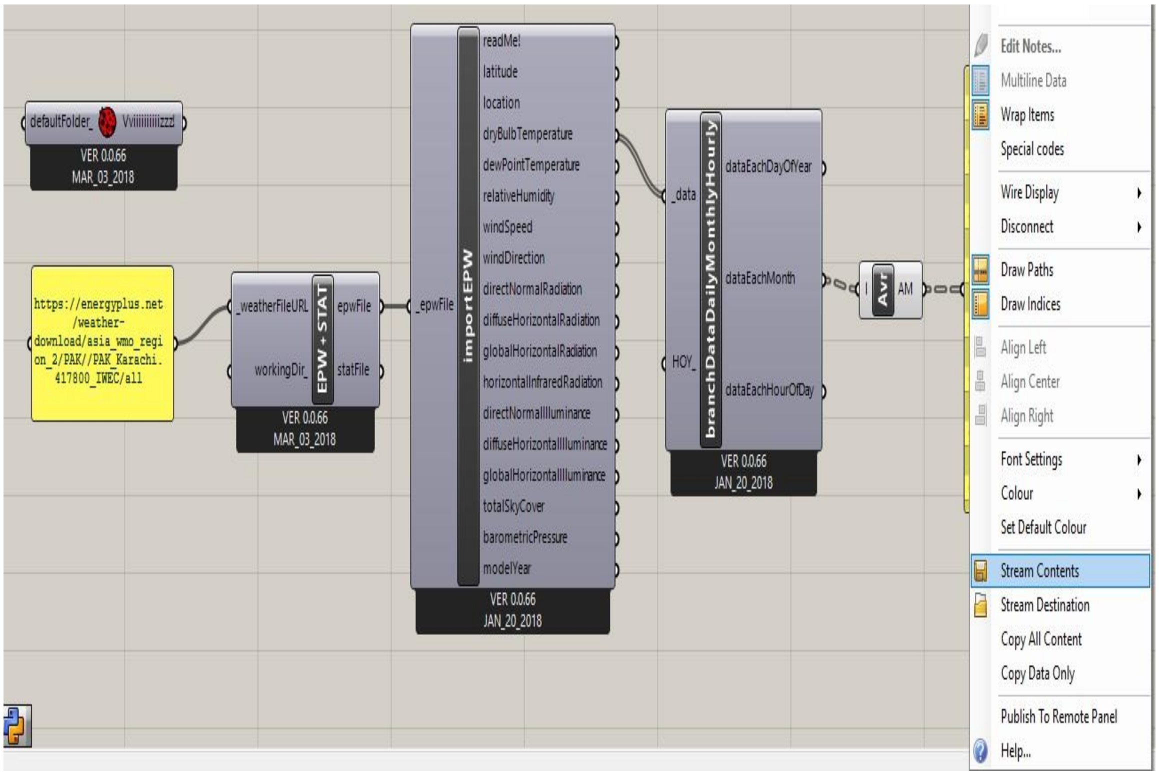

Fig. 4.4: Import of Monthly Dry Bulb Temperature to Excel

3.1 Import of Weather Data

As it can be seen that online weather data can be imported for the case of Karachi Pakistan by following the above procedure. This imported data has all kind of weather data like Dry Bulb Temperature, Dew Bulb Temperature, Relative Humidity, Global Horizontal Irradiation, Global Horizontal Illuminance, and Pressure etc. that can be exported to study its effects on PV System as illustrated in fig 4.1, 4.2, 4.3, & 4.4.

In Table 4.1, it can be seen that import of average monthly data for the case of Karachi, Pakistan is done using Rhino/Grasshopper.

TABLE 4.1
IMPORT OF AVERAGE MONTHLY WEATHER DATA FOR THE CASE OF KARACHI PAKISTAN USING RHINO/GRASSHOPPER

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

4.2 Building Environment Irradiation and Temperature

The Ladybug add-on was utilized to study and calculate the solar irradiance on the modules and temperature that affects the building per hour for the whole year. Ladybug contains different components that process weather data. By using Ladybug add-on, study of environment irradiations and temperature can be done for output results. On the other hand, this is a benefit when studying the number of irradiations and temperature available for the solar system mounted above the building.

In figure 4.5, it can be clearly seen by using Rhino/Grasshopper that most of the year has a high temperature in Karachi, which affect the solar panel performance.

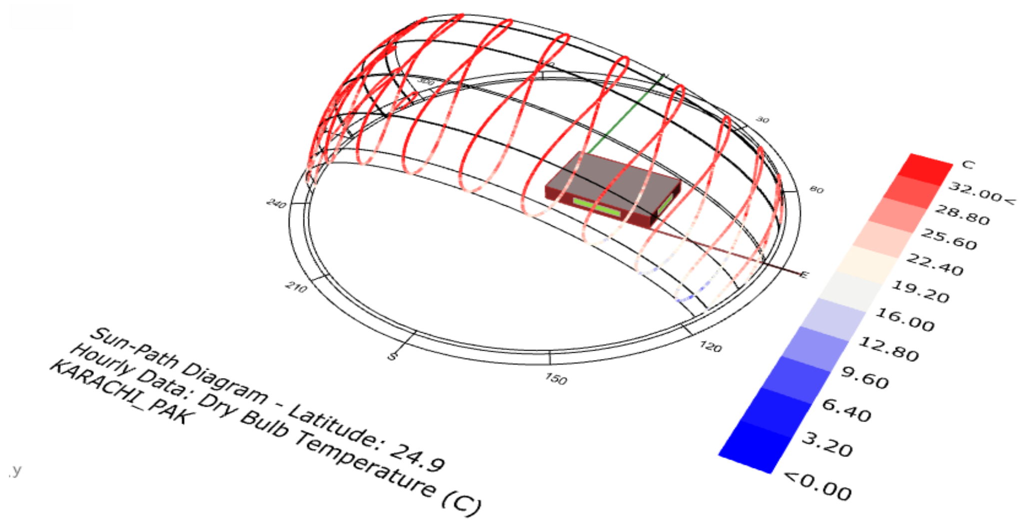

Fig. 4.5: Solar Path and Sun Positions for Degrees between 0 & 32 °C

We also know that the effective period is longer in summer where the daytime becomes longer as shown in figure 4.6 by using Rhino/Grasshopper. The total output values of temperature and irradiation are averaged over a monthly basis and then exported to an Excel file to be post-process as will be shown in the coming subsections.

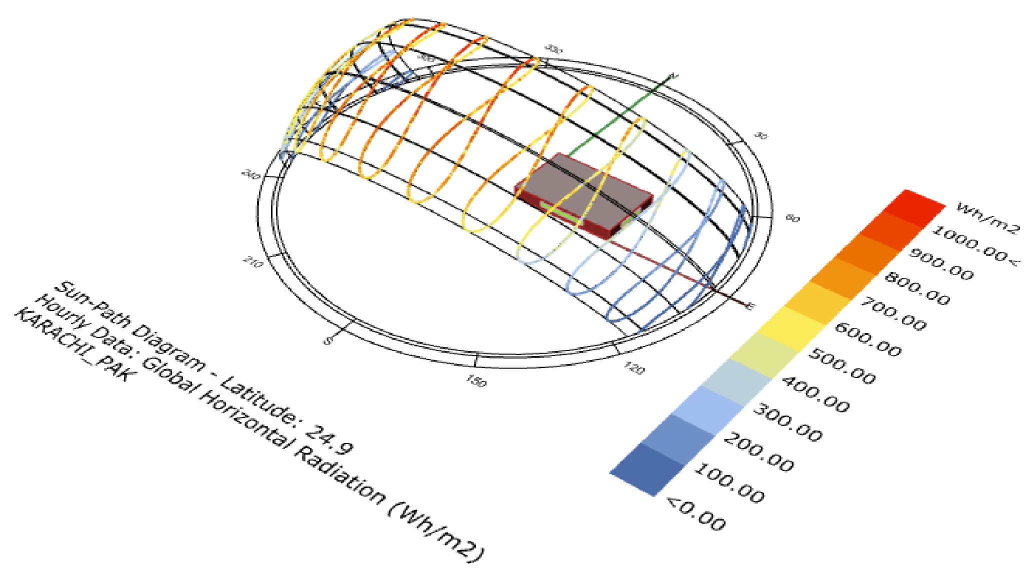

Fig. 4.6: Solar Path and Sun Positions for Irradiation between 0 & 1000Wh/m^2

Good to mention that further studies can be held to study part of the year, in which specific amount of irradiation and values of temperature are available. For example, if we want to have the values of temperature greater than 25 C and irradiation higher than 600, we can have the following figure 4.7.

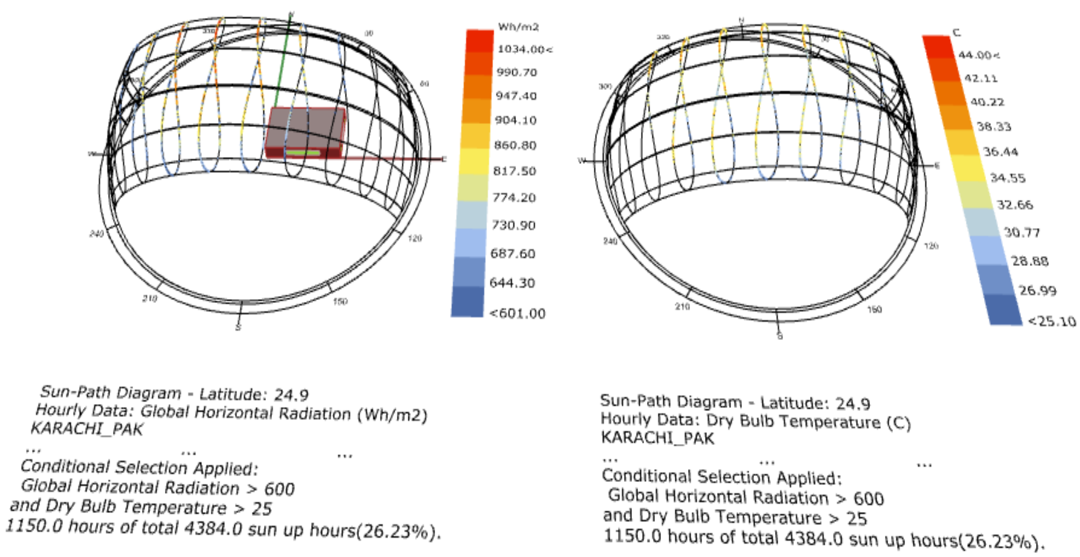

Fig. 4.7: Solar Path and Sun Positions for Irradiation higher than 600Wh/m^2 and Temperature greater than 25 °C

In this way, all kind of weather data like Dry Bulb Temperature, Dew Bulb Temperature, Relative Humidity, Global Horizontal Irradiation, Global Horizontal Illuminance, and Pressure etc. This weather data is utilized to study the solar electrical system and associated parameters for improving overall efficiency, which is the main area of novelty.

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, a simulation work is presented in which Karachi had been chosen to be the location of our study. A basic 3D geometry has been designed to have a PV system mounted on its roof. The geometry built with a property to be tuned in width and length to meet the desired area of several suggestions. In order to do that, the powerful 3D design program Rhinoceros was used. Moreover, the whole system, geometry, and PV system was constructed with the aid of the famous Rhino parametric plugin, Grasshopper. Rhinoceros is state of the art computer-aided design software, which can be used to generate complex geometries and 3D models. On the other hand, Grasshopper provides a visual programming language with a wide range of add-ons, such as Ladybug, Honeybee, EnergyPlus, Irradiation and many other useful add-ons that enhance the simulation performance.

In the Grasshopper file, all the parameters can be set and the simulations can be started. After the system is run for every simulation approach, the irradiation and temperature results are exported to excel files. These files are then imported via a Simulink PV cell figure 1, for extra post-processing in which the I-V and power curves are produced.

The Grasshopper simulation depends on two aspects, in order to enhance the PV output power, considering the same available irradiation and the same temperature.

First aspect: A fixed PV system is compared to a three-mode movable PV one with Vertical axis, Horizontal axis or Dual Axis modes.

Second aspect: Three PV module types are considered: Basic Crystalline-Silicon (c-Si) module, California Energy Commission (CEC) module, and Sandia module.

While the building energy and the irradiation simulations are conducted within Grasshopper, the PV calculations take place within Python. The capacity of this model can be changed as desired to get output results.

5.1 Output Power Results

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

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

In figure 5.1, the mode has changed over to fixed panels, Vertical axis tracker, Horizontal axis tracker and finally dual axis tracker, based on the data in shown in Table 5.1, in Kilowatts. The PV module had been chosen to be of Sandia type characteristics. As can be seen from the figure, the dual axes mode achieved the best performance over all the other types. On the other hand, it can be noticed that the vertical tracker, inclination auto-adaptation, achieved performance very near to the dual one in July, August and Sep. This means that in terms of cost, the system can be set to only vertically track in these months. Finally, the horizontal tracker and the fixed type exhibited the poorest performance.

TABLE 5.1

MONTHLY PV POWER PRODUCTION FOR SANDIA PV MODULE

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

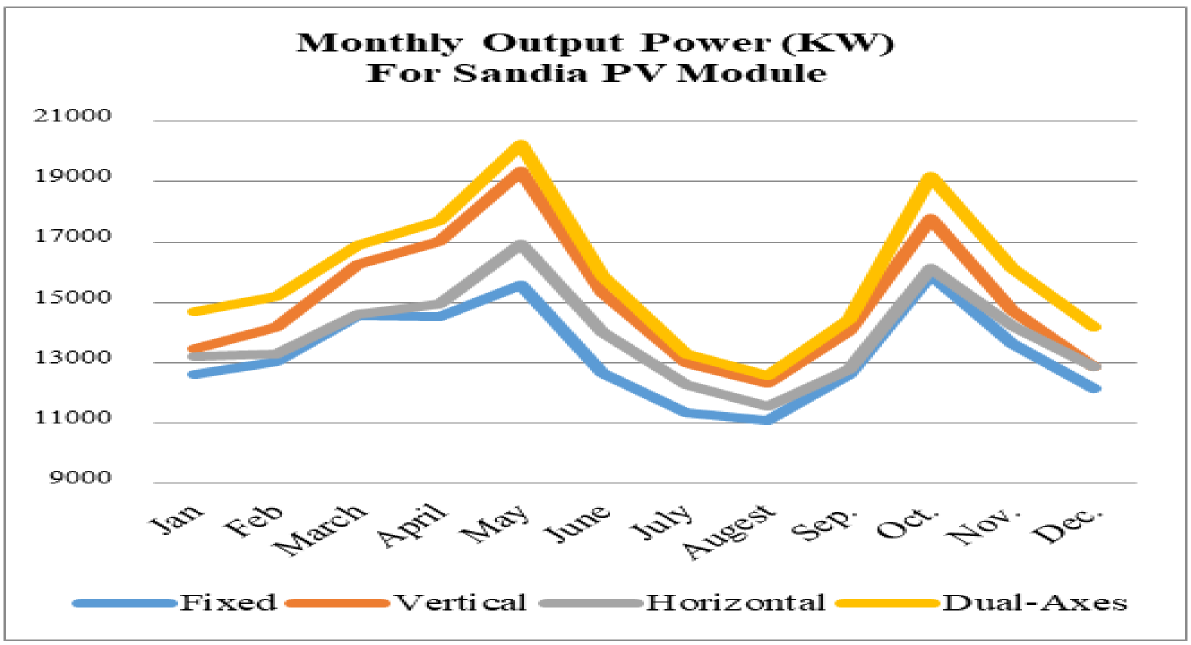

Fig.5.1: Monthly PV power production for Sandia PV Module

Similarly, the simulation had been run simplified, table 5.2 and CEC, table 5.3, PV modules. The dual axes maintain the best performance, as shown in figures 5.2 and 5.3. However, in the simplified module, the vertical and dual axes exhibit almost the same performance. Which means that, in terms of operation cost, the vertical tracker is a better choice if simplified PV module is to be chosen.

TABLE 5.2
MONTHLY PV POWER PRODUCTION FOR SIMPLIFIED PV MODULE

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

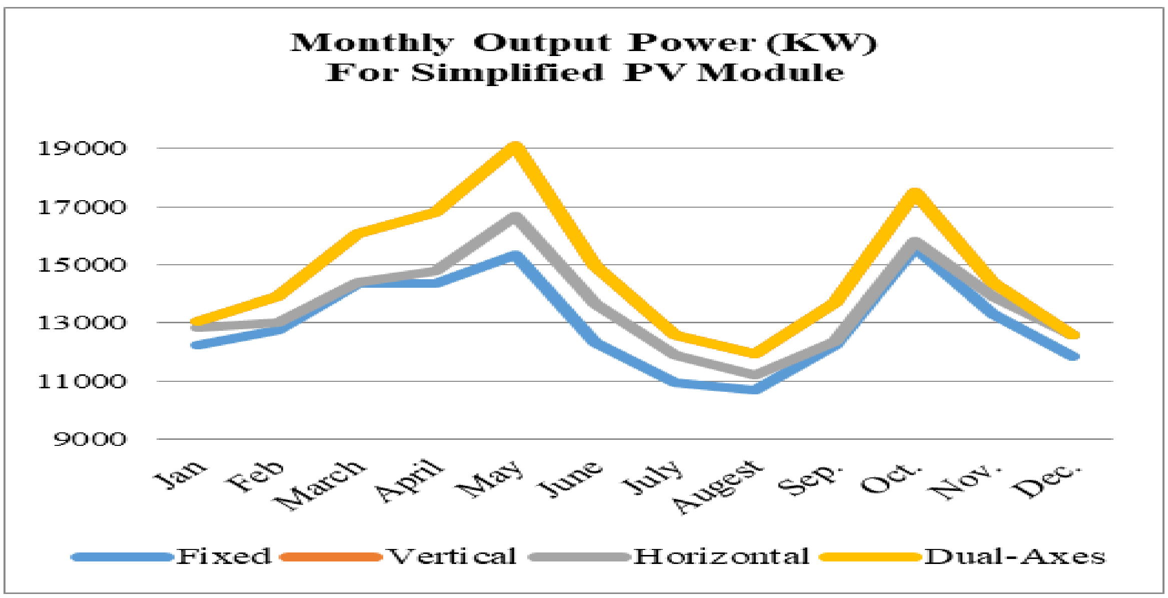

Fig. 5.2: Monthly power production for Simplified PV Module

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

TABLE 5.3
MONTHLY PV POWER PRODUCTION FOR SIMPLIFIED CEC MODULE

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

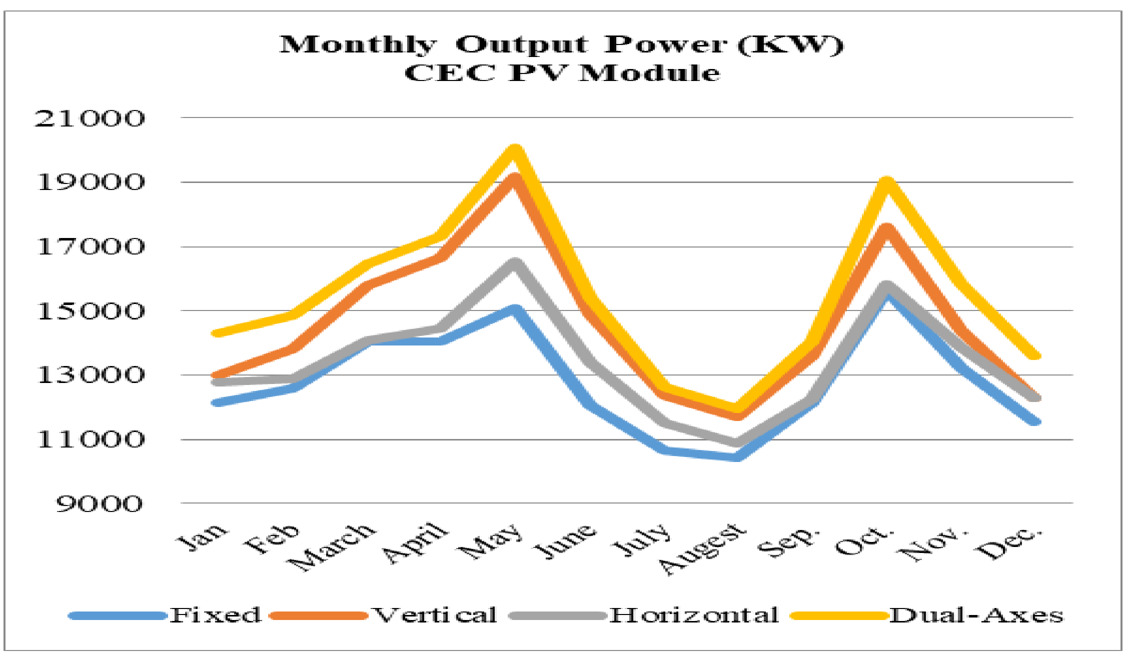

Fig.5.3: Monthly power production for CEC PV Module

2. Output Power Improvement by Changing the Type of the PV Module

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

A comparison between the PV modules types was held table 5.4, as shown in figure 5.4, considering the dual axes mode as a reference mode. The Sandia and CEC showed almost the same performance in terms of power production. Additionally, they perform better than the simplified module, especially, in winter and autumn, in which the performance gap becomes larger.

TABLE 5.4
MONTHLY PV POWER PRODUCTION FOR DIFFERENT PV MODULES CONSIDERING DUAL AXIS MODE

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

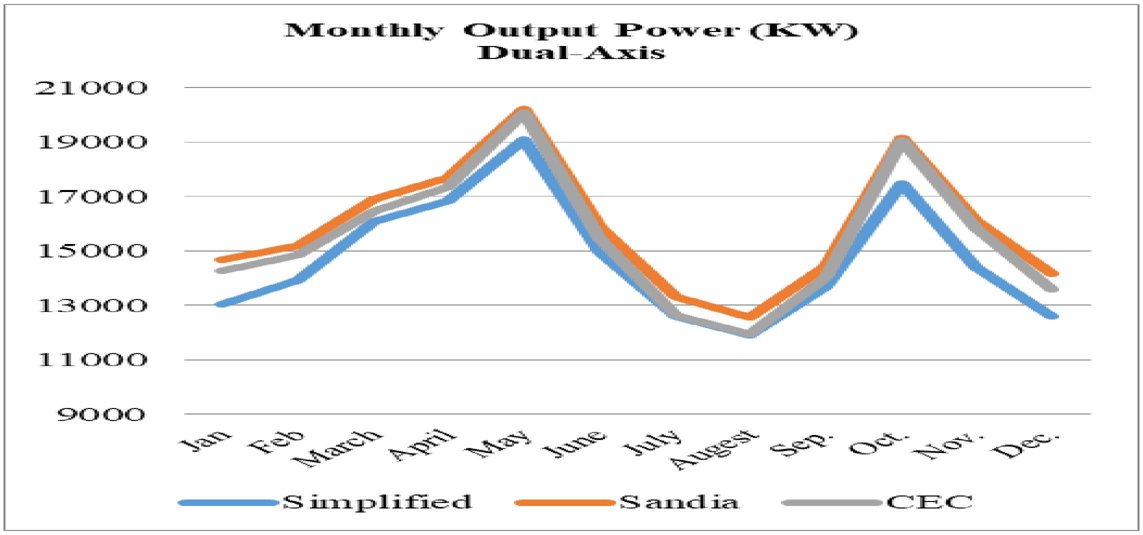

Fig. 5.4: Monthly power production for different PV Modules considering Dual Axis

Good to mention that although all of the three PV modules used in this modulation encounter the same amount of irradiation, their performance in terms of power production differs. It can be clearly depicted when compared on annual power production basis, as shown in figure 5.5. Sandia with dual axed mode produces the largest amount of annual power. The CEC and dual was the second-best choice. While the simplified fixed one was the worst, with amount less of about 20% of production.

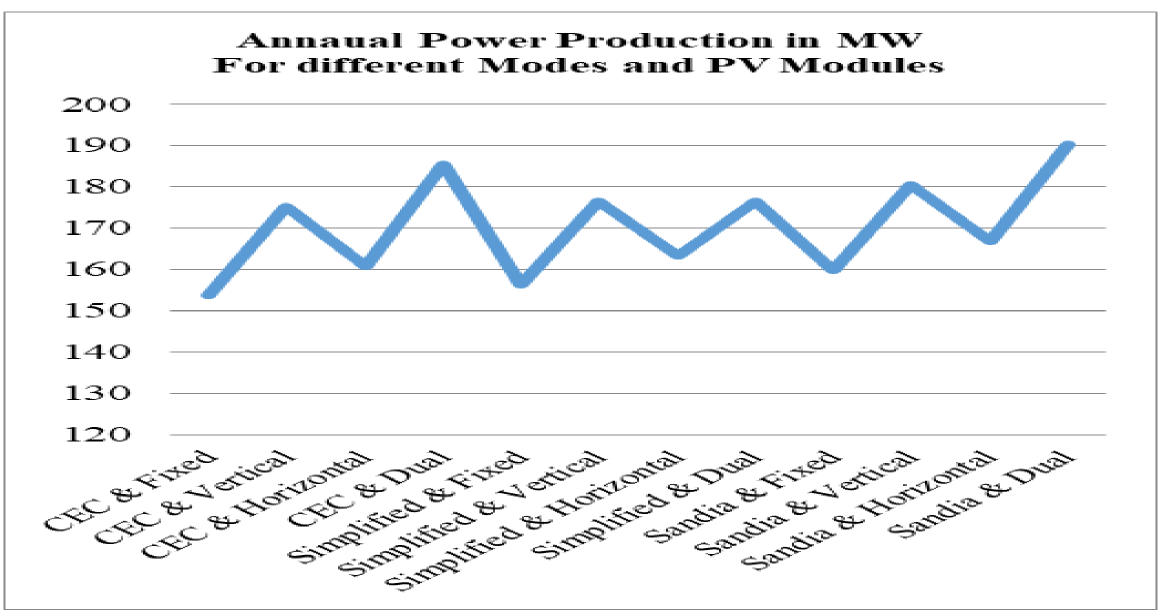

Fig.5.5: Annual power production for different Tracking Modes and PV Modules

5.2 Irradiation and Temperature Analysis

The main aim of this work was to enhance a PV system power output considering the same temperature and irradiation. The geometry roof surface encountered the same temperature and irradiation conditions, which had been obtained depending on official online data of Karachi. Therefore, the tracking solution had proposed to harvest and utilize as much solar irradiation as possible to increase the system efficiency and boost up the output power. The irradiation data is tabulated in table 5.5 summarizes the previous idea. It compared the fixed and tracking modes behavior to the same amount of irradiation of the building surface. As expected, the dual axes PV system harvests the largest amount of irradiation. So that, it produces the largest annual amount of power as seen in figure 5.6. The vertical tracker achieves the second annual rank of irradiation and power production. However, it can be noticed that during summer, the dual and vertical trackers harvest almost the same amount of irradiation. Horizontal tracker and fixed PV showed the least amounts of irradiation harvesting and power production.

TABLE 5.5

MONTHLY IRRADIATION HARVESTING FOR DIFFERENT SYSTEM MODES IN WH/M^2

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

Figure 5.6, summarizes the previous explained idea. It compared the fixed and tracking modes behavior to the same amount of irradiation of the building surface.

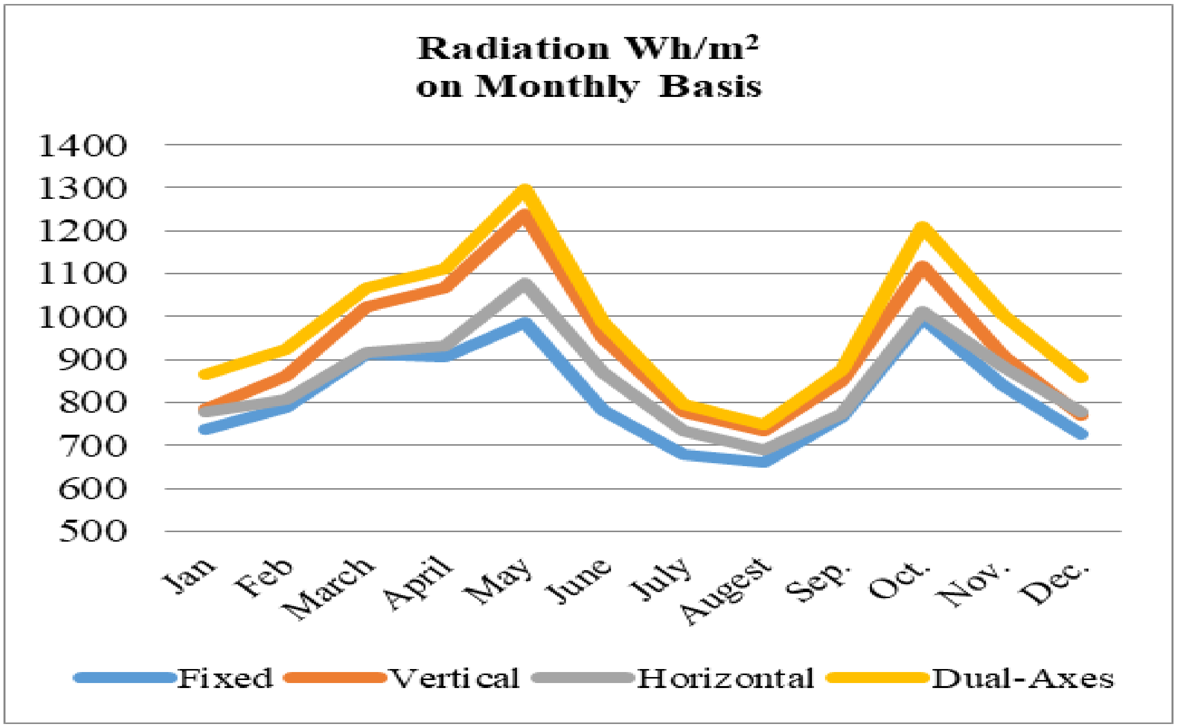

Fig.5.6: Monthly Irradiation harvesting for different System Modes in Wh/m^2

As expected, the dual axes PV system harvests the largest amount of irradiation. Therefore, it produces the largest annual amount of power as seen in the above figure. The vertical tracker achieves the second annual rank of irradiation and power production. Further in figure 5.7, comparing the same mode of operation for different type. We can see for example for vertical mode, the Sandia converts the same amount of irradiation for a larger amount of power than simplified and CEC modules. This gives a significant indication of the importance of PV type selection before construction.

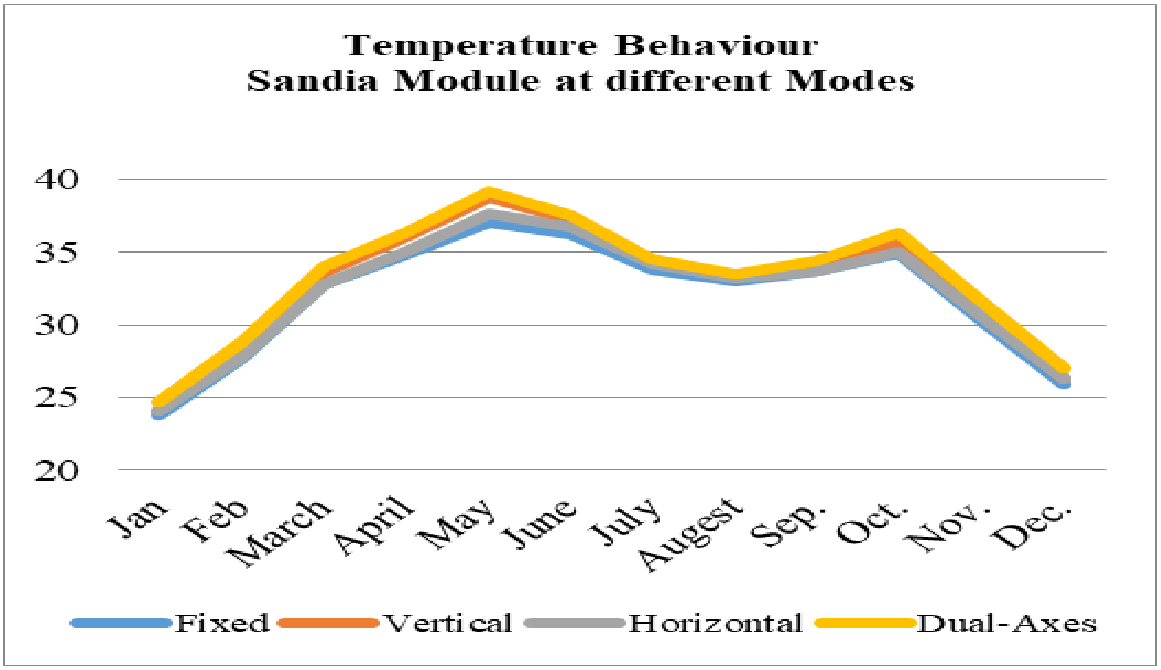

Fig.5.7: Temperature Behavior of Sandia Module at Different Modes

In figures 5.8, the effect of temperature on the PV system is examined. There were slight differences in the temperature of the PV surfaces. Compared to the previous results, it can be concluded that despite of the slight temperature rising in Sandia type and dual axes modules, their power production was the highest amongst the other options.

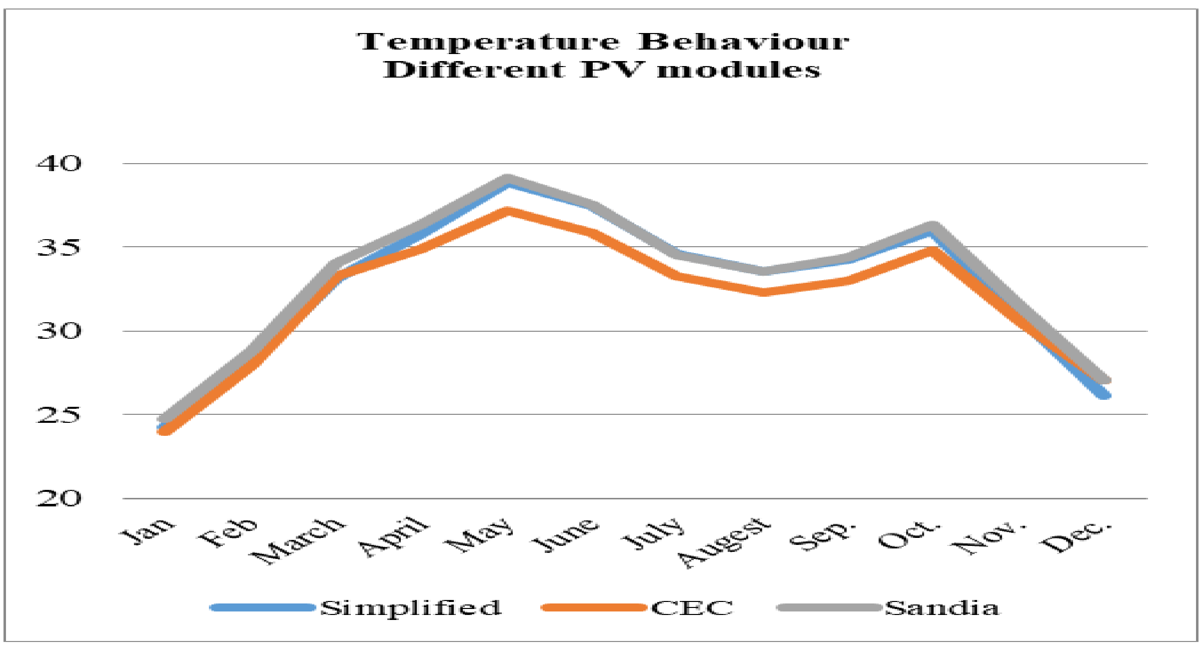

Fig.5.8: PV Module Type's Temperature Behavior

5.3 PV Cell Simulation using Simulink/MATLAB

In order to investigate the power curve and the V-I characteristics of the designed PV system, the output temperatures, and solar irradiation, produced by the grasshopper simulation, were exported to a PV cell, shown in figure 5.9.

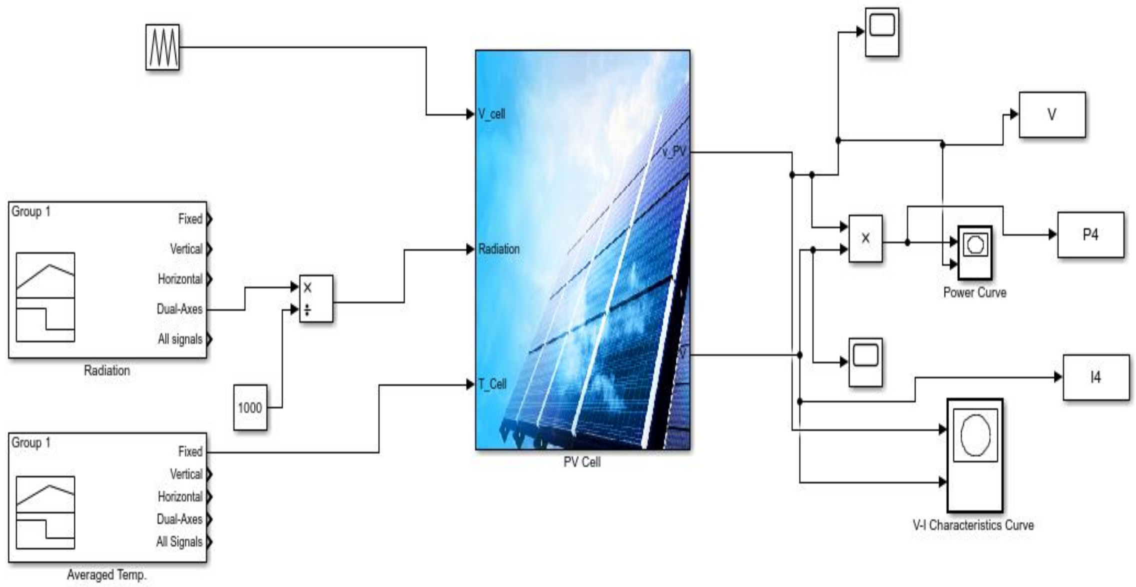

Fig 5.9: PV Cell- Simulink/MATLAB

The electrical model of the photovoltaic cell was built following the standard equivalent circuit model to calculate the I-V and power curves with a single diode, one shunt, and one series resistance, using Simulink, MATLAB.

The irradiation and temperature were averaged over the whole year in Excel files, then exported to Simulink. The irradiation was normalized, dividing by 1000 as shown in figure 5.9, to meet the Standard Test Conditions (STC) approach. The simulation was run four times then; the results had exported to MATLAB workspace. The plots in figures 5.10 and 5.11 were then generated for better visualization of the results.

The power and I-V characteristics curves are common ways between researches that give an indication of the system behavior in terms of maximum point power tracker (MPPT) and power production, respectively.

The harvested

irradiation of the Fixed, Vertical, Horizontal and dual PV modes at a temperature of 31.55 Co was fed to the PV cell to be investigated. In figure 5.10, the dual axes mode gives the maximum power point, as expected from the grasshopper simulation. The vertical comes next then the horizontal and fixed modes.

The similar arrangement of power production can be easily noticed in figure 5.11. More investigation can be done for each mode temperature. However, the harvested energy and power production will stay show the same behavior as explained above.

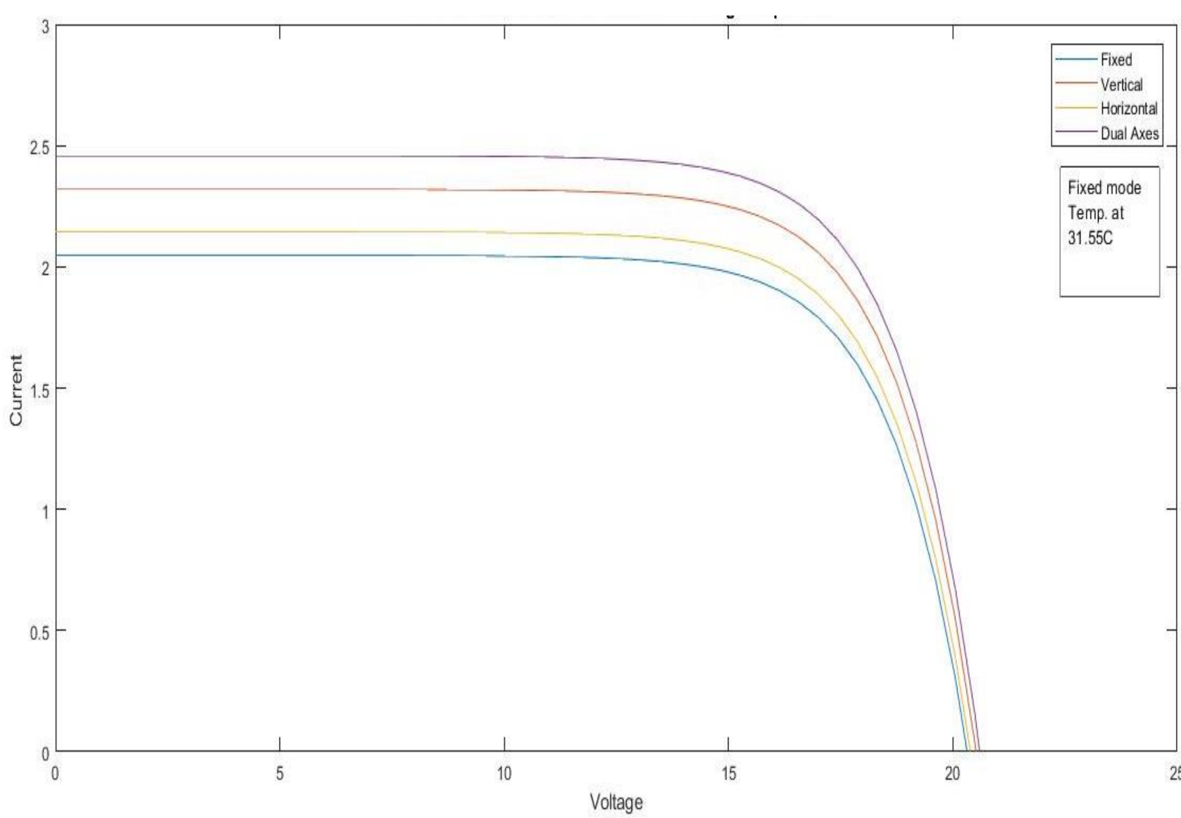

Fig 5.10: I-V Characteristics- Variable Irradiation

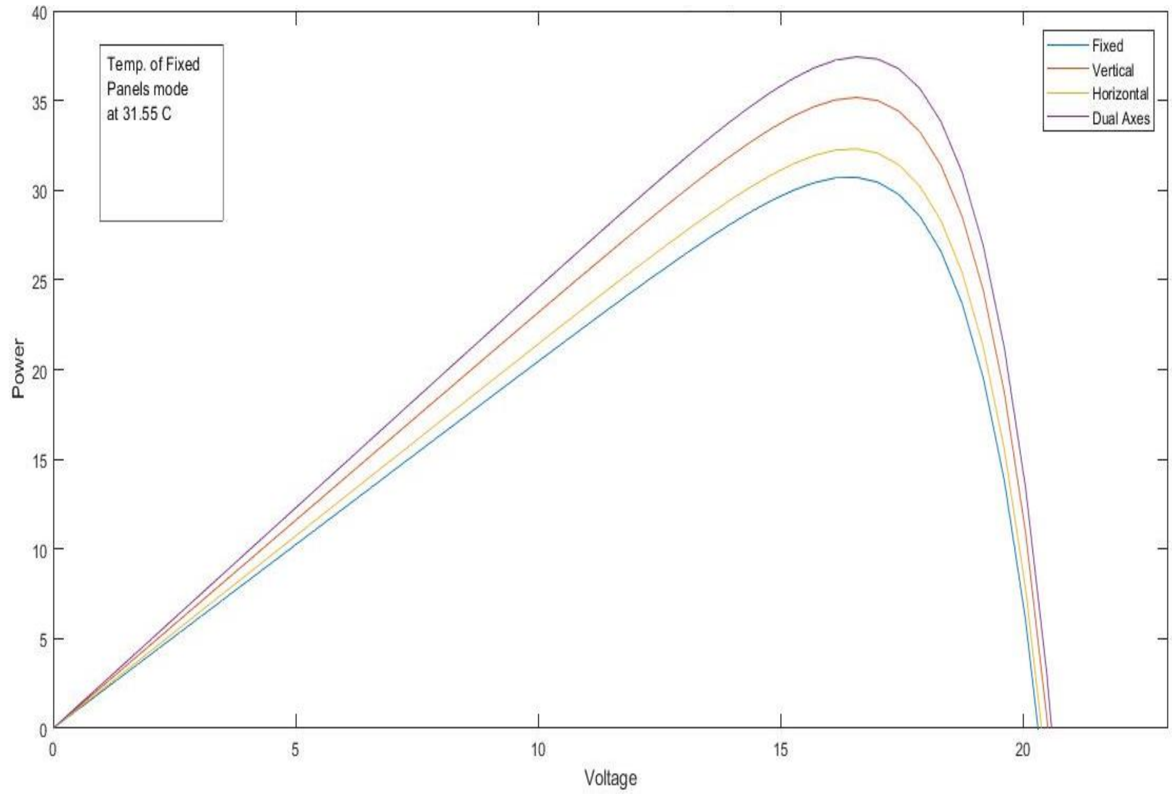

Fig. 5.11: Power Curve - Variable Irradiation

5.4 Cost of Tracking System

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

CHAPTER 6

CONCLUSION AND FUTURE WORK

In this thesis, the problem of enhancing a Solar PV System, considering the same environment condition was investigated. The main aim was to boost up the annual power production while having the same amount of solar radiation and the same temperature conditions. In order to maintain such environment, the Rhinoceros power 3D program with its valuable Grasshopper plugin were employed. Two approaches were proposed to maximize the solar radiation harvesting process:

Solar Irradiation Tracker System: In which the PV system is equipped with actuators that enable the panels to track the sun for the optimal amount of radiation, depending on the annual weather data available for Pakistan. The tracking was studied for three cases, Horizontal, Vertical and Dual axes trackers. It was found that this technique was very useful to boost the power production in most of the months of the year, over the fixed PV system approach.

PV Module Types: The act of changing the PV module type was investigated. Two types were used over the conventional Silicon-Crystalline, simplified module: CEC and Sandia modules. The results were very promising, in which a significant enhancement was noted in both radiation harvesting and power production over the simplified module.

This work opens the gate widely in front of different trends and future study in which the 3D tools and weather data were utilized to study solar electrical system, which is the main area of novelty. Future studies are studying the effect of shadowing, depending on its annual data and solar sun path, on the solar systems production and choose the optimal locations and suggestions to minimize the effect of shadowing.

Moreover, further studies on the effect of wind and wind speed on PV system construction and production can be held. Last but not least, the Architecture design and specs can be studied to apply adaptive solar panels as building facades, which yield to power production and also to building shading. Based on intensive work, this can lead to reduce the power consumption of heating and cooling systems while having a clean source of energy that contribute to the free power sources.

REFERENCES

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

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

[3] Q. A. H. Al-Naser, N. M. A. Al-Barghoothi and N. A. S. Al-Ali, "The Effect of Temperature Variations on Solar Cell Efficiency," International Journal of Engineering, Business and Enterprise Applications, vol. 4, no. 2, pp. 108-112, 2013.

[4] AN. H. Zaini, M. Z. Ab Kadir, M. Izadi, N. I. Ahmad, M. A. M Radzi and N. Azis, "The Effect of Temperature on a Mono-crystalline Solar PV Panel," in IEEE Conference on Energy Conversion (CENCON), pp. 249-253,2015.

[5] P. Singh and N. M. Ravindra, "Temperature dependence of solar cell performance-an analysis," Solar Energy Materials and Solar Cells, vol. 101, pp. 36-45, 2012.

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

[7] J.Ahmad, F. Spertino, A. Ciocia and P. Di Leo, "A Maximum Power Point Tracker for Module Integrated PV Systems under Rapidly Changing Irradiance Conditions," in International Conference on Smart Grid and Clean Energy Technologies, 2015.

[8] S.Chander, A. Purohit, A. Sharma, Arvind, S. P. Nehra and M. S. Dhaka, "A study on photovoltaic parameters of mono-crystalline silicon solar cell with cell temperature," Energy Reports 1 Elsevier, pp. 104-109, 22 March 2015.

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

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

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

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

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

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

[15] P. Arjyadharal, Ali S.M, and J. Chitralekha, “Analysis of solarPV cell performance with changing irradiance and temperature,”International Journal of Engineering and Computer Science 2.1,vol. 1, pp. 214-220, 2013.

[16] http://www.bosch-solarenergy.de

[17] http://www.yinglisolar.com/en

[18] http://global.kyocera.com

[19] http://www.sharp-world.com

[20] P. Sivaraman, A. Nirmalkumar. “A New Method of MPP-Maximum Power Point Tracking for Maximizing the Power Generation from an SPV Plant.” Journal of Scientific & Industrial Research, vol. 74, pp. 411-415, July. 2015.

[21] R. Arulmurugan, N. S. Vanitha. “Optimal Desig C to DC Boost Converter with Closed Loop Control PID Mechanism for High Voltage Photovoltaic Application.” International Journal of Power Electronics and Drive System (IJPEDS), vol.2, No.4, pp. 434-444, December. 2012.

[22] V. J. Fesharaki, M.dehghani and V. J.Fesharaki. “The Effect of Temperature on Photovoltaic Cell Efficiency,” International Conference on Emerging Trends in Energy Conservation-ETEC, pp. 20-21,Tehran, Iran, November. 2011.

[23] S.Alsadi, B.Alsayid. “MPP-Maximum Power Point Tracking Simulation for Photovoltaic Systems Using Perturb and Observe Algorithm.” International Journal of Engineering and Innovative Technology (IJEIT), vol. 2, Issue. 6, December 2012.

[24] A.A. Elbaset, H.Ali, M.Abd-El Sattar “A Modified Perturb and Observe Algorithm for MPP-Maximum Power Point Tracking of Photovoltaic System Using Buck-Boost

Converter." Journal of Engineering Sciences Assiut University Faculty of Engineering, vol. 43, Issue. 3, PP. 344, May. 2015.