Statistical Analysis and Performance Evaluation of Quaid-e-Azam Solar Park Compared with Designed Systems Using RETScreen, PVsyst and PVWatts.

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Session 2017-2019

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A Thesis Submitted to the US-Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTER of SCIENCE

in

ENERGY SYSTEMS ENGINEERING

US-Pakistan Center for Advanced Studies in Energy (USPCAS-E)

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September 2021

THESIS ACCEPTANCE CERTIFICATE

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Acknowledgements

All praise to the great **Allah Almighty** who has bestowed me with the opportunity to seek knowledge and enabled me to fulfill the obligation to explore the world of science up to my maximum limits.

I would like to express my sincere gratitude to my research supervisor **Dr._Sehar Shakir** and co-supervisor **Dr. Parvez Akhter** for their motivation, continuous support, guidance and knowledge. Both have guided me during my journey of research. Working under their supervision was a great pleasure and joy which has expanded by vision.

I am also thankful to my GEC members, Dr. Adeel Waqas and Dr. Nadia Shahzad for sparing their precious time from their busy schedules, for suggestions and moral support. Besides this I would like to acknowledge the USPCAS-E staff and faculty for being extremely cooperative.

In the end, I would acknowledge the hard work of my parents as without their support and unconditional affection I would have never survived the whole period of MS. They have always encouraged and believed in me which proved as a driving force during the difficult times in my research phase.

Abstract

In this study solar system of DC Rating 100 MW located at Bahawalpur, Punjab, Pakistan is designed with three different tools which are RETScreen, PVsyst and PVWatts. Most softwares use weather data provided by NASA. That is why it is important to compare vital parameters of weather data used by software should be similar with the actual data. For this purpose and to check validity and prediction capability of different softwares this study is carried out. In this study these designed systems are compared with system installed at Quaid-e-Azam solar power plant near Bahawalpur, Punjab, Pakistan having DC Rating 100 MW. Temperature and humidity has inverse effect on efficiency of solar panels as temperature increases efficiency of solar panels decreases similarly output decrease with increase in humidity. Irradiance and wind speed have direct effect on output of solar panels with increase in irradiance. Output is increased with more wind speed heat losses of panels are less and yield is more. Comparing the output for whole year with RETScreen, PVsyst and PVWatts it might be concluded that PVWatts results are closer to recorded values of solar power plant. RETScreen output is 2nd close to recorded generation. This study also help to evaluate different tilt angles of panels for maximum output for semi and quarterly annual tracking system as well as for the fixed system. This study also help to choose proper tool for sizing purpose and by avoiding over sizing and under sizing conditions energy future demands could be met more precisely. Comparison between designed and installed systems output for the whole year is made and all the sizing parameters are kept same for each system as that of installed system and results obtained from PVWatts stood closest to output of installed system.

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Chapter 1

Introduction

Demand of electricity is increasing day by day and to meet this exponentially growing demand of energy various sources are utilized. It is predicted that total energy demand would reach about 778 Etta Joule by 2035 [1]. Coal is still the largest source of energy for production of electricity. Millions of tons of coal and other hydrocarbons are burnt daily to meet this giant demand of energy. These fossil fuels are not only finite and costly but also produce worst effects on environment. Millions of tons of greenhouse gasses are liberated which harms protective layer of Ozone [2]. All these harmful effects of fossil fuels urge power sector to rely significantly on cleaner sources of energy more and more. Oil and gas sector is still the biggest source of energy production despite all these harmful effects and finite sources. Energy plays vital role in development of a country. Moreover statics show that all developed countries have excessive energy available for their industrial, commercial and domestic sectors. Energy sector is significantly affected by prices of fossil fuels which alternate very often. Extraction and transportation of fossil fuels is also a big headache to deal with, it requires special care and treatment to avoid any harmful incident.

1.1 Renewable Energy

Significant growth of renewable energy has been seen in the last decade[3]. There are various advantages if exploiting renewable energy resources over other conventional sources of energy production urging people to employ renewable energy more and more. Unlike fossil fuels renewable energy resource are infinite and are present everywhere on earth. International Energy Agency (IEA) has calculated world energy statics from 1971 to year 2017 shown in Figure 1.1 and 1.2[1].

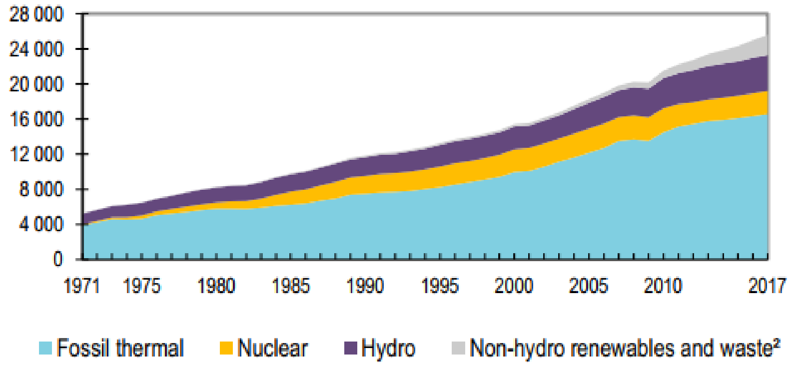


Figure 1.1 Power Generation by different sources [1]

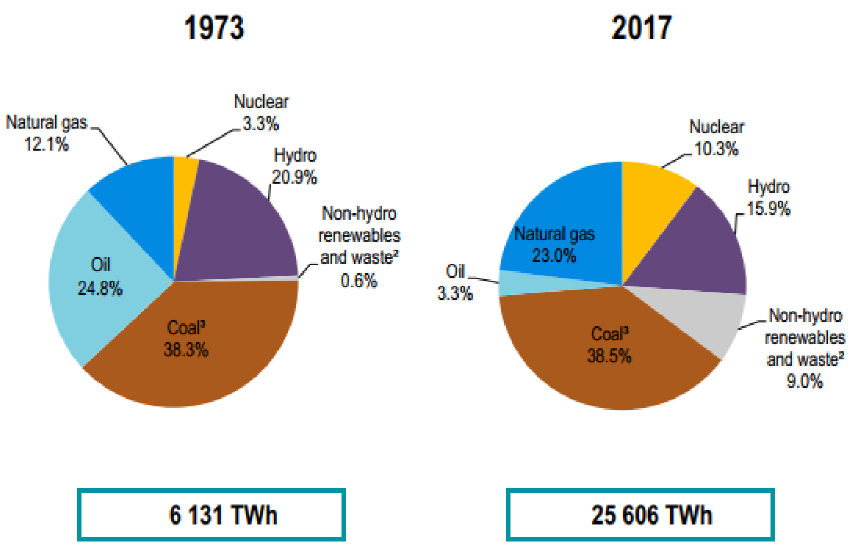


Figure 1.2 Comparison of different sources for power generation[1]

1.2 Solar Energy

Solar panels are constituted of solar cells usually made of semiconductor material. Elements with four electrons in their valence shell are called semiconductors. Pure semiconductor is called intrinsic semiconductor and doped semiconductor is called extrinsic semiconductor. There are two types of doping elements Pentavalent and Trivalent. These types of semiconductors are further discussed later. N type semiconductor has excess of free electrons that is why it is called Donor while P type has tendency to accept electron that is why it is called acceptor. When P type and N type semiconductor layers joint a PN junction is formed. Potential barrier is form due to PN junction which hinders charges to move freely from the junction [4]. P type layer is made very thin so that sufficient sun light could reach PN junction and when these cells are exposed to sunlight potential difference is created between N and P layers of solar cell. P type layer act as anode and used for positive output terminal while N type layer act as cathode and used for negative output terminal. Pictorial representation of a PN Junction is shown in Figure 1.3

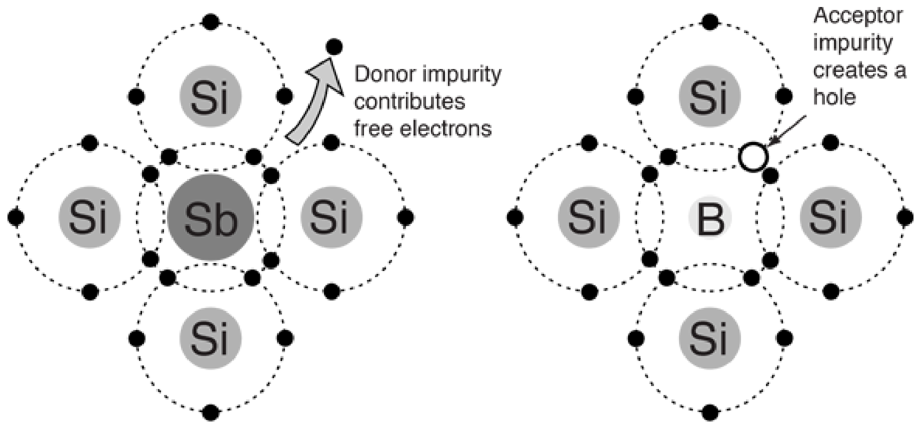


Figure 1.3 Concept of acceptor and donor atoms[4]

1.3 Issues related to PV Sizing

The optimal sizing of the PV system depends upon two main factors. The first factor deals with the revenue and other factor deals with the performance of the system[5]. The first case is the optimal sizing of the system having additional revenue to be greater than that of the variable costs of additional unit's installed capacity. The main influence in the designing of the system to obtain the efficient system is

1. Location as well as solar irradiance of the location in which the system is being installed
2. The electricity consumption of the system and number of appliances which are to be operated for particular duration
3. Relation among the PV generation and load
4. Difference in the levels of the pricing i.e. energy produced to energy consumed

1.4 System Designing with RETScreen Expert

RETScreen is a tool designed by Canadian government. It can be used easily by anyone anywhere in the world. It is used to evaluate and design prototypes of models of clean energy, solar and wind energy systems. RETScreen Expert is very competitive tool to design on grid or off grid systems. It uses weather data provided by NASA. In this version users are able to save and print in professional versions. Without these functions, this tool can also be used without any subscription or activation charges.

1.4.1 Getting started with RETScreen

When RETScreen software is loaded plenty of options like "File, Location, Facility, Energy, Cost, Emission, Finance, Risk, Data, Analysis and Report" can be seen at the top left corner of RETScreen Software. Using these options detailed analysis of any type of system of clean energy can be performed. Energy generation estimation can be done with weather data selection of that specific place where the system is needed to be installed.

1.4.2 System designing with PVsyst

PVSyst is a powerful tool to analyze and size Photovoltaic systems. PVsyst is capable of designing and data analysis of on grid, off grid, DC grid used for transport and pumping Photovoltaic system. It is powerful tool to estimate output in monthly or evenly in hourly basis. Weather files containing data of specific location are pre-installed and if weather file of desired location is not given in pre-installed weather data, desirable location data can be imported if internet facility is available

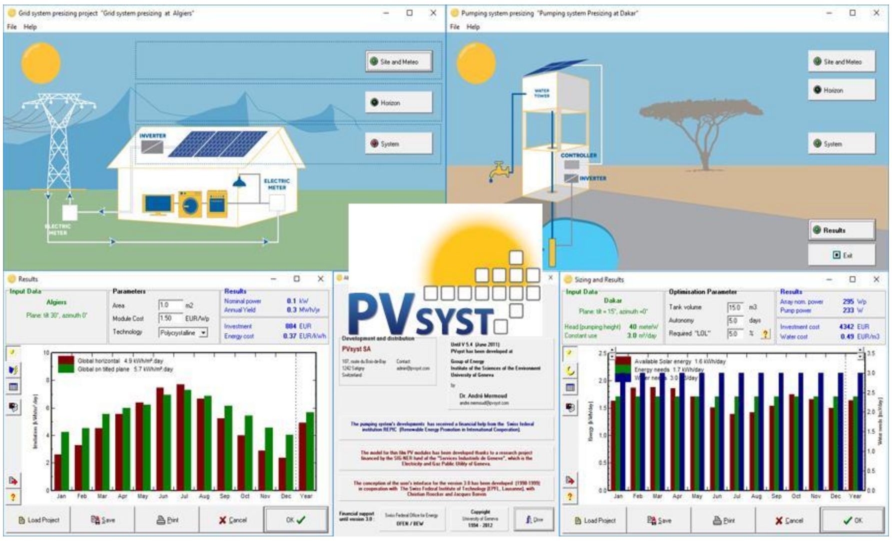


Figure 1.4 PVSyst

1.5 World Solar Energy Statics

Solar energy is a renewable source of energy. Solar Energy is harvested by sunlight and is converted into Electrical Energy by using Solar cells[6]. Different technologies are used to convert sunlight into Electrical energy. Photovoltaic technology is more famous among all these technologies[7]. Statics given by IEA providing details about statics of solar energy used are shown in shown in Figure 1.5 and 1.6.

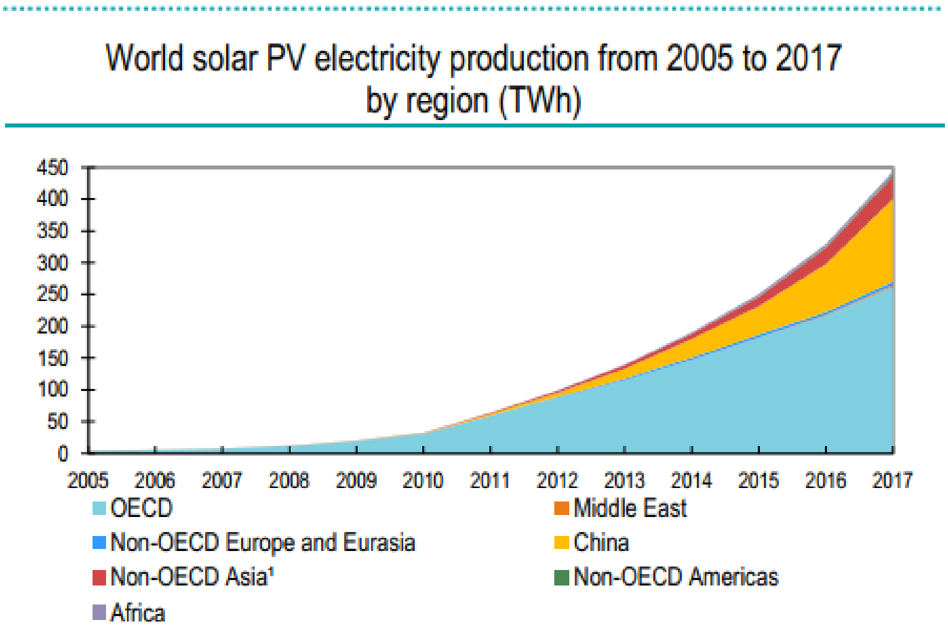


Figure 1.5 Production of Solar Energy by different countries[1]

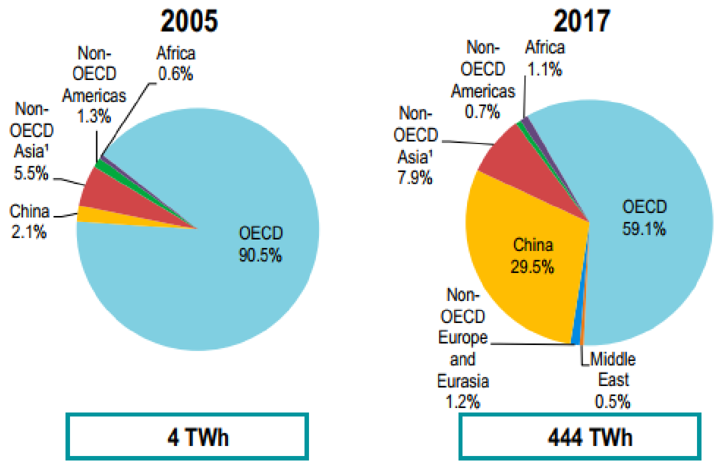


Figure 1.6 Comparison of Production of Solar Energy by different countries in 2005 and 2017[1]

1.7 Energy Conversion and Feed in Tariff

Solar panels provide DC output of 12V. Domestic appliance operates on 220V or 110V AC. AC loads cannot be driven by DC output of solar panels. Inverters are used to convert DC to AC. The field of electronics has made significant progress and now solar energy producers are not only producing electricity to meet their energy demands but are also able to sell excess of energy produced. Excessive energy from private producers can now be injected back to national grid and special two way meters are used which accounts the flow of energy towards the consumer and the energy fed to national grid from the consumer [8]. Special prices are introduced for energy exporters. Prices are set for each unit (KWh) of energy is known as feed in tariff.

1.8 Problem Statement

Increasing demand of electricity and extensive use of solar energy to meet our energy demands and also selling excess electricity generated by solar system by two way metering enforce the optimum sizing of solar generation system to meet our requirements. Sizing plays an important role to predict output from solar generation throughout the year. There are many softwares available for sizing of solar system but due to some unknown reasons output predicted by one software does not equate with the output generated by another software for the same system keeping all parameters same. This malfunctioning of software may lead us to over sizing or under sizing of solar system, which may lead to financial loss. This rises the questions on credibility of different sizing softwares. To overcome this problem this study is conducted so that more sufficient sizing software can be identified by comparing output for the whole year with the installed system of Quaid-e-Azam solar park[10]. Along with sizing systems comparison in this study we'll find out the most optimum angles for semi or quadrate tracking solar systems.

1.9 Summary

In this chapter trends of world energy are discussed, conventional generation was dominating in late 90s and coal was most dominating source for production of electricity, with the time energy generation sector is adopting renewable energy and solar energy now has significant share in world energy production and is increasing day by day. This study is carried out to identify accurate solar system sizing tool to ensure precise system sizing and avoiding over or under sizing of solar generation systems.

References

[1] IEA, World Energy Balances 2019, International Energy Agency, Paris, 2019.

[2] IRENA, Renewable Capacity Statistics, IRENA, Abu Dhabi, 2017(http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenu ID=36&Cat ID=141&SubcatID= 3831.)

[3] A Snapshot of Global PV (1992–2014), International Energy Agency (2015).

[4] Global Market Outlook for Solar Power 2015–2019, SolarPower Europe (2015).

[5] M. M. Rafique and S. Rehman, National energy scenario of Pakistan — Current status, future alternatives, and institutional infrastructure: an overview, Renewable and Sustainable Energy Reviews, 69 (2017) 156–167.

[6] D.W. van der Meer, J. Widen, J. Munkhammar, Review on probabilistic forecasting of photovoltaic power production and electricity consumption, Renew. Sustain. Energy Rev. 81 (2018) 1484–1512

[7] U. Zafar, et al., An overview of implemented renewable energy policy of Pakistan, Renew. Sustain. Energy Rev. 82 (2018) 654–665.

[8] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, 2014 [Core Writing Team, Pachauri P.K. and Meyer, L.A.]

[9] M. Mendonça, Feed-in Tariffs: Accelerating the Deployment of Renewable Energy, Routledge, 2010.

[10] Quaid-e-Azam Solar Power, Quaid-e-Azam Solar Power (Pvt.) Limited, Pakistan (2020).

Chapter 2

Literature Review

Solar system comprises of various system components such as solar panels, inverters, connecting wires, batteries, mounting structure etc. Some additional components like switches, fuses, circuit breakers are also used. Solar panels provide DC output and for daily use we required AC voltage therefore inverters are used to invert DC into AC of desired magnitude and frequency. This conversion process is no 100% efficient and some power is used by electronics components of inverters. Modern inverters are efficient enough to give output with efficiency ranging up to 98%. Various studies have been carried out to evaluate and analyze the performance of solar photovoltaic system. In this chapter factors effecting performance of solar system will be discussed along with some related work already done by the scholars.

2.1 Research Work Overview

Various research works have been carried out related to this study. Some similar studies are discussed.

2.1.1 Solar Potential Assessment using PVSyst

C.P. Kandasamy carried out a similar study in which simulation of a grid-connected solar photovoltaic system is designed using PVsyst software and it's performance is evaluated. It also contains information about power losses due temperature, conversion DC-AC etc. Keeping in view the results, viability of installing 1 MW solar power project is conversed by comparison of solar PV production and life cycle cost analysis of some places in of Tamilnadu, India. [11]

2.1.2 Solar Photovoltaic (PV) System Sizing

P G Nikhil designed system to calculate overall energy generated from grid connected photovoltaic system for specified location and capacity. In this model performance at hourly interval and optimum distribution units based on the cost function are combined. The simulation is verified using accumulative generation data from a 2 MW PV power plant. Further, the application of the simulation algorithm is demonstrated by evaluating sizing requirements of 1 M.W grid connected photovoltaic system at Tamilnadu (Vellore district). Nominal operating Cell Temperature NOCT effect on the system is also evaluated.[12]

2.1.3 PV System for Residential Purpose

L. N. Khairlybayeva conducted a study which deals with the energy production of PV system for the residential purpose. Location is Mangystau region of Kazakhstan. System has rating of 4.6 k Wp. The analysis has been made using feed in tariff for Kazakhstan per kWh and RETScreen is used to design system. The comparison has been made for solar power, hydroelectric power and wind power for year 2013 and 2014.That study shows the PV system to be best on the basis of insulation and its attractive market price as compared to that of conventional power system[13].

2.1.4 Stand Alone PV System using RETScreen

Research has been done by the utilization of RETScreen software for the designing of standalone PV system hybrid system and pumping system. The research provides the information of that a model for the previous system that impacts the efficiency on the basis of reference temperature and the temperature coefficient of the module. In addition to that, the model developed for upgrade system is also discussed containing this battery backup without incorporation of any great connection [14].

2.2 Designing of PV System

Some auxiliary components are also the cause of losses in solar photovoltaic system. Losses related to components like fuses, circuit breakers, connecting wires, digital displays, sensors, etc. also affect system performance.

For the designing of the PV system having grid connection, it is to be noted that the main components are solar cells which are further divided into different categories, the junction box which contains the connection of the strings which are joined together at that point. Next is the distribution box and the main panel that combines DC and DC through the inverter. Following that comes a net meter which monitors the incoming and outgoing electrical energy from the system and into the system. The load is connected after the inverter. Further parameters are discussed in subtopics.

2.2.1 Factors affecting solar irradiance

Elevation is an important factor which affects level of solar irradiance. Similarly, air mass is also an important factor which affects the solar irradiance received by specific place. Places with clear environment and clean air will have more solar irradiance [15]. Frequent clouds can also decrease irradiance level. Incidence angle also plays vital role in measure of solar irradiance falling on an object. If plane or object is tilted, it receives less solar irradiance while if plane or object is directly facing the sun then it receives more solar irradiance[16]. Another important factor is daytime, incidence angle of sun keeps on changing throughout the day and throughout the year as well. When sun rises sunlight makes specific angle with absorbing object as the day time passes this angle keeps changing and maximum sunlight is received at noon and after noon angle again keeps on changing until sunset.

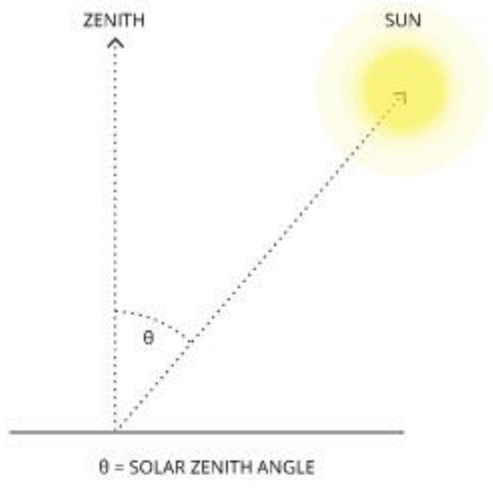


Figure 2.1 Calculation of Solar angle[16]

Anula Khare proposes an optimal sizing methodology for a solar photovoltaic (SPV) system considering lifetime cost requirements. The aim of the design is optimal sizing of SPV system, which is obtained by calculating solar photovoltaic system output power at certain location, taking into account the calculated optimal number of solar photovoltaic modules, optimal number of inverters, optimal tilt angle, for a given dimension of land. This design is aimed for minimizing the annual cost of grid integrated solar photovoltaic system over its life or years of operation. Results obtained are compared with the results of TVACPSO, RANDIWPSO, PVSYST and RETScreen results. It shows that TVIWPSO is giving maximum value of objective function along with other quality results shown in figure 2.3 [17]

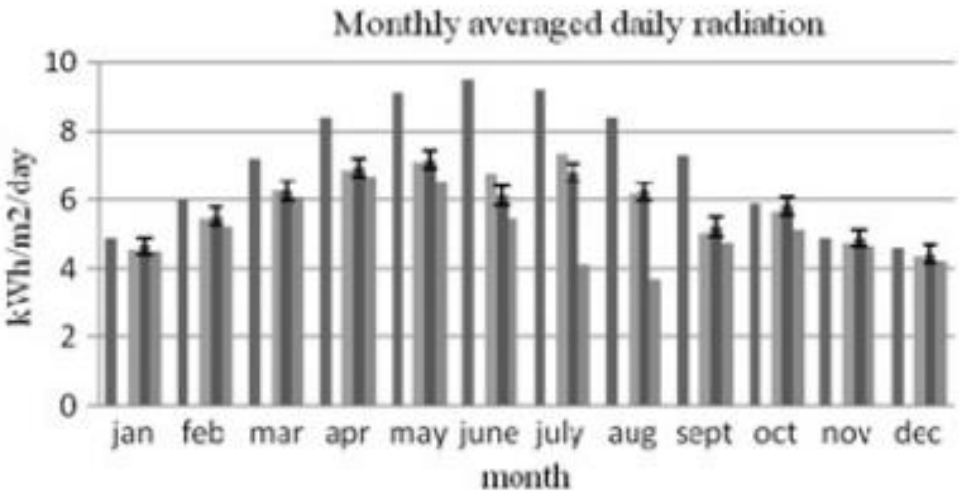


Figure 2.2 Study Results

The introduction of renewable energy sources into the power grid is associated with significant costs. Here, an optimal localization and sizing of solar photovoltaic power generation plants in a power network are analyzed. Genetic algorithms are used to solve the optimization problem [18].

Sizing related issues are significant for domestic and commercial buyers of photovoltaic systems in Africa. Many of the installed systems are undersized and the system doesn't fulfill the electricity demand of offices and homes. To avoid the issue of under sizing or oversizing of the system, a smart calculator is developed. This smart calculator calculates the power and tilt angle for respective location. It can also calculate the size of batteries. The output is also compared with the installed system outputs. The results from the calculator were also compared with Solar Installation catalogs from a Solar Installation company in Nigeria to check for similarities and differences [18].

An algorithm which estimate whole energy generated through grid connected PV system at any location and capacity, is developed.[19].

2.2.2 Factors effecting Solar Energy System

There are many other factors which affect the performance of solar system. Weather conditions are the most important factor that influences the performance of solar system [20]. Solar irradiance is the key factor that is evaluated first to find out feasibility of solar system for a specific location. Following picture is helpful to understand the effects of weather conditions on performance of solar cells.

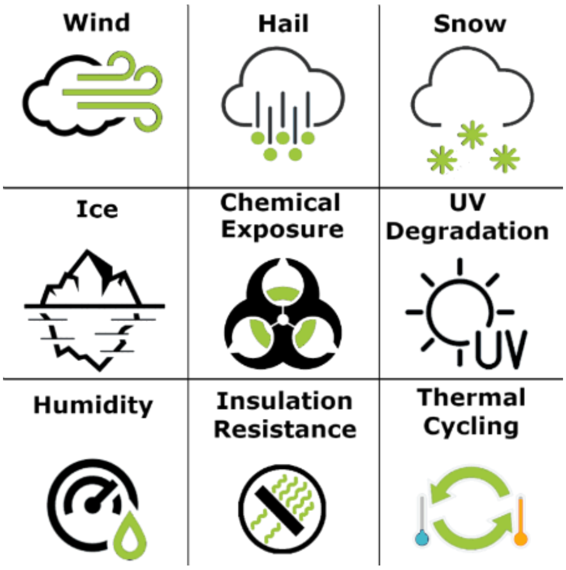


Figure 2.3 Weather conditions affecting solar power

Temperature is another important factor which affects the performance of solar system. Apparently areas with solar rich radiations are considered as more productive for solar photovoltaic generation but in fact hot areas are not that suitable for solar systems. High temperature affects the performance of solar systems very badly [21]. Humidity also affects badly on life and performance of solar panels. Wind speed helps solar panels to radiate so heat absorbed by solar panels hence efficiency is increased with increased wind speed[22]. Distribution of losses in solar system is shown in figure 2.4

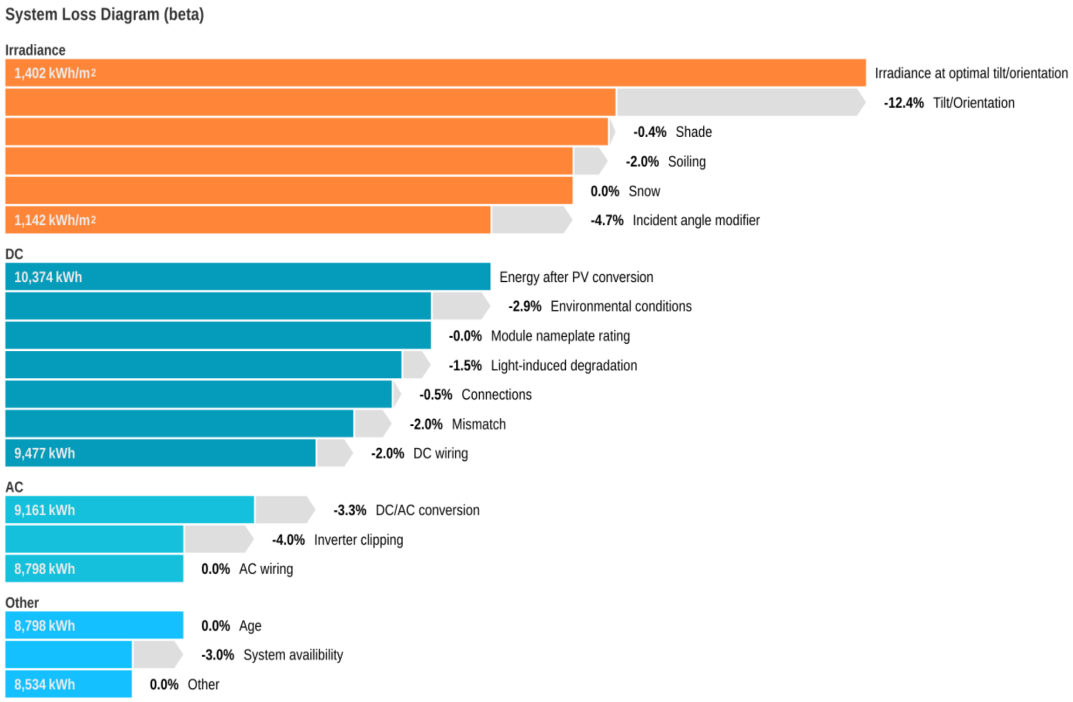


Figure 2.4 Energy loss diagram by different equipment in the system [23]

2.2.3 Effect of Temperature

Many studies have been carried out to evaluate the effects of temperature and other factors. In this study it is observed that, for 1°C increase in (NOCT) for the same power PV module, the plant capacity factor drops by 0.35 %.[s2015] The increase in NOCT directly influence the cell temperature Solar panels work in presence of sun light and usually highest temperature of environment is marked at noon when sun is directly faced by solar panels. Depending upon absorbing material temperature of solar panels may rise up to 70 °C or even more in areas where weather is too hot in summer [24].

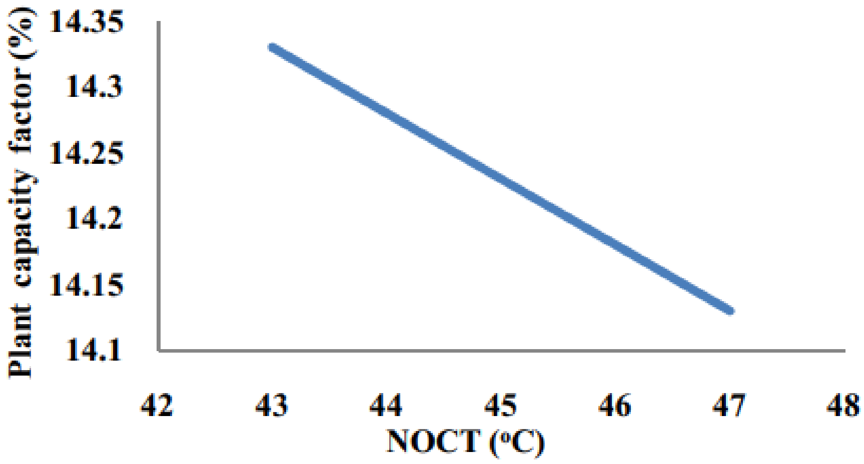


Figure 2.5 Plant capacity factor against NOCT in ℃

In a study reported in literature [25], quantitative effect of temperature on performance of different types of semiconductors is analyzed. Temperature range used from room temperature to 350 K. Effect of given temperature range is shown in Table 2.1.

Table 2.1 Temperature Impact on Efficiencies of the Materials

Sr. No.	Solar Cell Type	Efficiency at Room Temperature	Efficiency at 350 K	Effect of temperature for given range
1	Silicon Cell	25.84%	20.95%	4.89%
2	GaAS Cell	28.01%	23.95%	4.06%
3	CdTe Cell	18.87%	17.20%	1.67%

It is clear that for this range of temperature Cadmium Telluride cells are least effected by increase in temperature but still Gallium Arsenide and Silicon solar cells have better efficiency for this temperature range. Although Silicon is most often used for commercial and domestic scale due to availability and cheap prices of Silicon solar cells.

Temperature has negative effect on performance of solar cells. All output parameters of solar cell are affected by change in temperature. Open circuit voltages are inversely related with temperature, as temperature of panel in increased temperature of cell also increases and open circuit voltages of cell are decreased. Short circuit current is somehow increased with increase in temperature but this increasing effect is not as dominant as decreasing effect of voltages. Power out of solar cell is affected with temperature in same manner as voltages are affected. Power out of solar cell is multiple of open circuit voltage and short circuit current, though increase in short circuit current is observed with increase in temperature but this increase in short circuit current in not as dominant as decrease in open circuit voltages due to increase in temperature. Since decreasing of output voltage is dominant effect of increased temperature hence output power of solar cell is decreased with increase in temperature as shown in Figure 2.6.

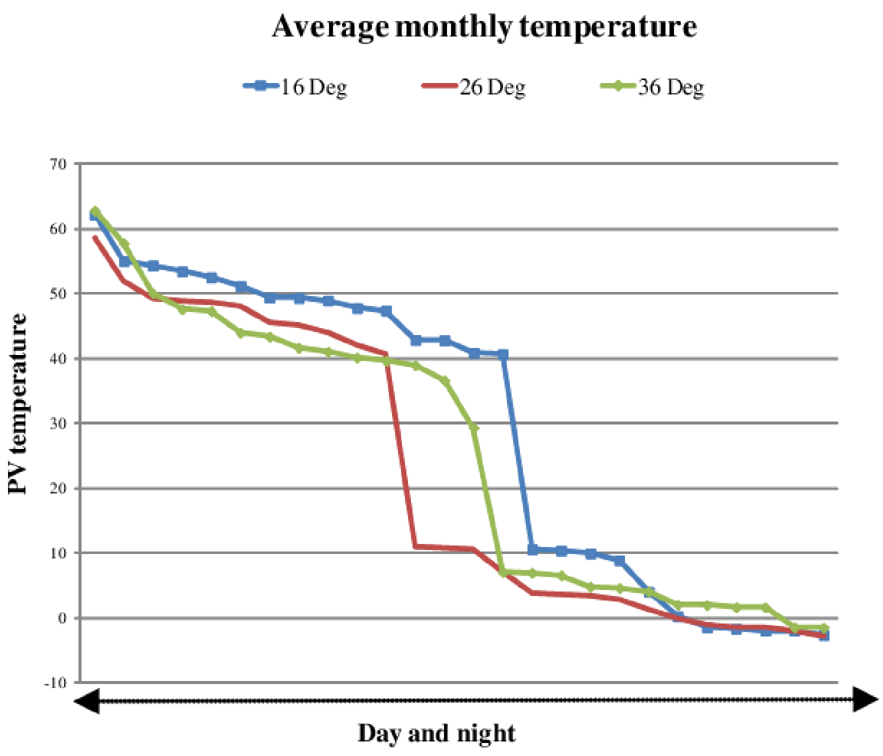


Figure 2.6 Average monthly temperature details of solar panel across 24 hours [27]

Cell temperature of solar panel is nearly equivalent to the temperature of back side of PV panel. PV panel temperature not only varies seasonally but also varies significantly during daytime and night. Panel temperature reaches its peak at or after noon depending upon the intensity of sun light falling.

Environmental temperature of specific location is usually less than 50 ^{o}C and the temperature of solar panel is always more than ambient temperature during day time when sun light is falling on it. Depending upon intensity of sun light and absorption of sun light facing material of solar panel the temperature of solar panel may get significantly high and reaches much more than ambient temperature value, in this scenario wind helps solar panels to take heat away from solar panels that is why solar panels are mounted in special manner so that maximum heat could be radiated by using wind. In this way wind is helpful to improve the efficiency of solar panels.

2.2.4 Tilt angle

Tilt angle plays vital role in output of solar panels. Usually solar panels are installed with optimum angle so that maximum possible output is obtained. Tracking is a costly system that is why optimum angle is important if tracking is not adopted. Solar incident angle keeps changing throughout the day and throughout the year. Path of sun keeps changing each day, deviation of sun is called Declination Angle and it has range of ± 23.45°.

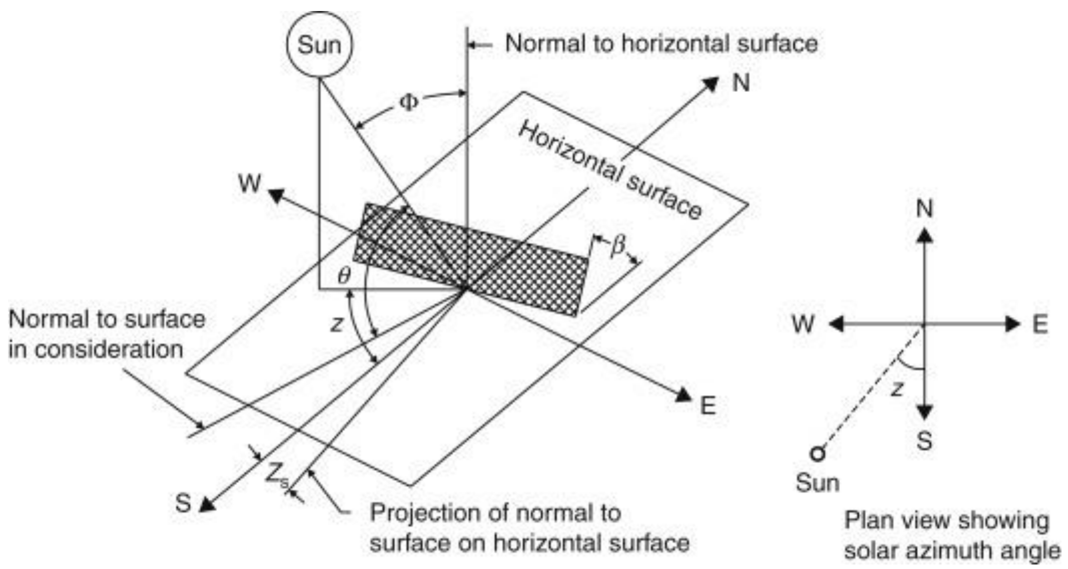


Figure 2.7 Tilt angle according to Solar Irradiance [28]

β =surface tilt angle from horizontal, $\beta = 0$ for horizontal surface.

Z_s =surface azimuth angle between the normal to the surface from true south, westward is designated as positive.

Declination Angle is the angle of displacement of from plane of equator [angle 2018]. It is denoted by δ. It can be calculated by using equation given below.

Where "n" is the number of day i.e. 1st January is taken as 1 and 31st December is taken as 365.

2.2.5 Irradiance on tilted surface

Plane on which irradiance is falling is not horizontal all the time, tracking is a costly technique to always track the sun that is why optimum tilt is figured out for specific location and total irradiance falling on a tilted plane or object can be found if irradiance value on horizontal surface is known [28]. Irradiance on tilted surface can be found using formula shown in Figure 2.8

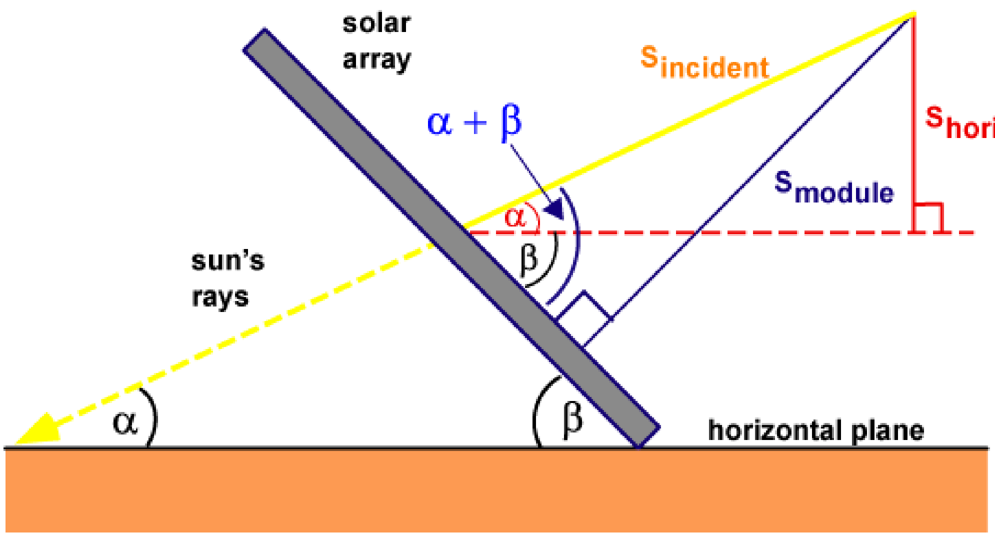


Figure 2.8 Irradiance impact on solar panel

$$S_{horizontal} = S_{incident} \sin\alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin\alpha}$$

2.2.6 Tracking

Tracking technique is adopted to maintain etiquette angle between sun and desired absorbing object. Tracking is done with specific interval of time. It is a costly technique adopted by solar system installers for maximum efficiency. Cost of this technique makes it non impressive for most users of solar energy, due to this reason an optimum angle is calculated at which maximum possible irradiance is received for respective location without any costly technique of tracking[28]. This angle varies place to place with respect to coordinates and elevation of that location.

2.2.7 Summer Solstice

It is also known as longest day of the year. When North Pole of sun is tilted closest to sun that day is called summer solstice. 21^{st}, 22^{nd} or 23^{rd} day of month of June is observed as summer solstice. At this day declination angle is + 23.45°.[29]

2.2.8 Winter Solstice

It is also known as shortest day of the year. When North Pole of sun is tilted farthest from sun that day is called summer solstice. 21^{st}, 22^{nd} or 23^{rd} day of month of December is observed as winter solstice. At this day declination angle is -23.45°[29].

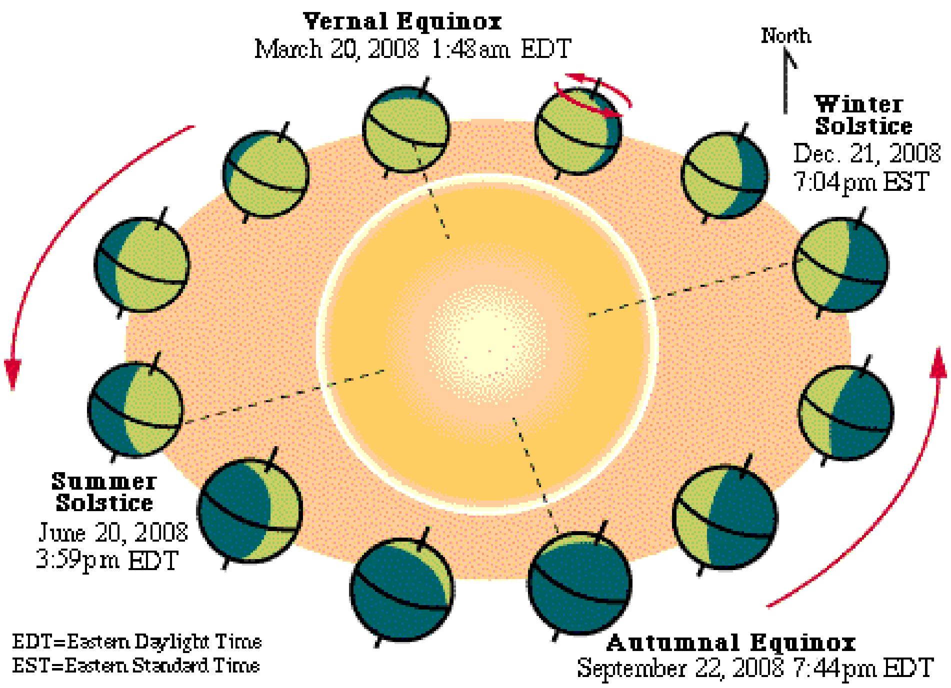


Figure 2.9 Equinox and Solstice all over the year [25]

2.2.9 Equinox

Length of day also keeps changing throughout the year. It does not mean that time taken by earth to complete its rotation around sun is changed or the time taken to complete one spin is changed but the factor on which length of day is calculated is sun shine hour. In summer sun shine is observed for more period than that in winter. In between these two solstice days two days of equal time of night and day, are observed which are termed as "**Equinox"**[30]. These days are observed normally on 21st September and March. Incidence angle of sun light keeps on changing throughout the day and sun shine hours also changes with change in season.

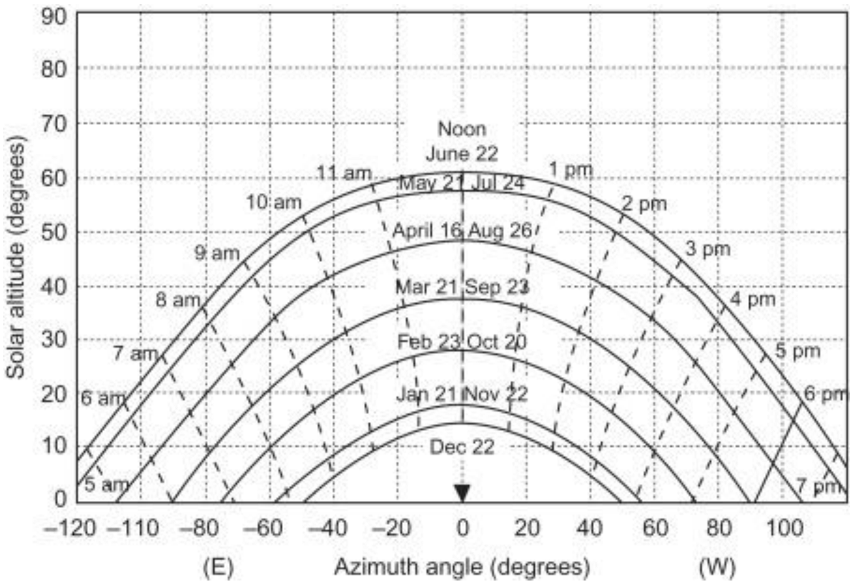


Figure 2.10 Solar Irradiance against Azimuth[28]

2.2.10 Inverter Losses

DC to AC conversion also involves some losses. Modern inverters are much efficient, and some inverters are efficient enough to reach efficiency of 98% without effecting output power quality or rating[30]. These losses are negligible when solar system ranges up to kilo watts ratings, but these losses should be accounted when installing system of capacity of MW.

2.2.11 Battery

Domestic solar systems are usually installed with storage capacity in the form of batteries. Lead Acid Batteries or Gel Electrolyte batteries are usually preferred. Battery banks are installed to provide backup for the dark days when the generation in not up to the mark of demand of energy. This energy storage in batteries in not an efficient process and on half of the energy delivered to batteries can be retrieved.

2.2.12 Soiling and aging of Panels

Output of solar panels is decreased with time. This is due to aging of solar panels. Weak junction and degradation of solar panels with the loss of transparency of upper lamination glass of solar panels, intensity of solar light reaching the solar cells is decreased hence the output of solar panels is decreased [30].

Soiling also lessen the output power supplied by solar panels. Our environment is not clean and tiny particles of dust and other impurities form a layer on glass of solar panels and hinder solar light to reach solar cell which result in decrease of output power of solar panels.

2.3 Construction and working of Solar cells

N type semiconductor has excess of free electrons that is why it is called Donor while P type has tendency to accept electron that is why it is called acceptor. When P type and N type semiconductor layers joint a PN junction is formed. Potential barrier is form due to PN junction which hinders charges to move freely from the junction. P type layer is made very thin so that sufficient sun light could reach PN junction and when these cells are exposed to sunlight potential difference is created between N and P layers of solar cell. P type layer act as anode and act as positive output terminal, usually layer of P type has Nickel ring around it and positive terminal output is taken from it, while N type layer act as cathode and negative terminal of output is taken from cathode. Lower back side of N type layer has metallic contact attached with it providing negative output terminal of solar cell. Construction of solar cell is shown in figure 2.11

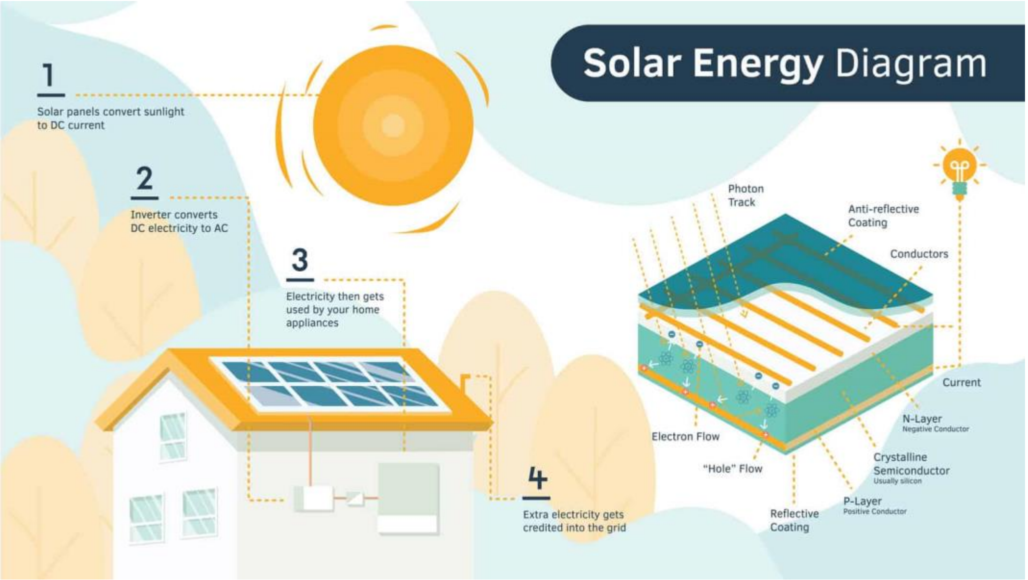


Figure 2.11 Operation of Solar Energy System

2.4 Solar Cell to Solar Panel

A single solar cell does not have sufficient output power to provide useful amount of energy that is why solar cells are connected is different arrangements to get desired output of current and voltage. Single solar cell has output voltage around 0.5V open circuit voltages and different rating of short circuit current. Solar panels usually have 12 volts output with different ratings of output current by connecting different number of cells in series or parallel arrangement. Metallic sheet is connected at back side of solar cells which provide mechanical strength to cells and connect different cells in desired arrangement as well while upper portion of cells which in needed to be exposed to sun light are laminated with the help of transparent glass so that cells are protected from physical damage and reach of sunlight to solar cells is made possible as well. This solar panel is then encapsulated is special way to ensure the mechanical strength of solar panels and output is taken from positive and negative terminal present at the back of solar panel. When cells are connected in series a panel is formed and when a panel is connected in series an array is formed as shown in figure 2.12

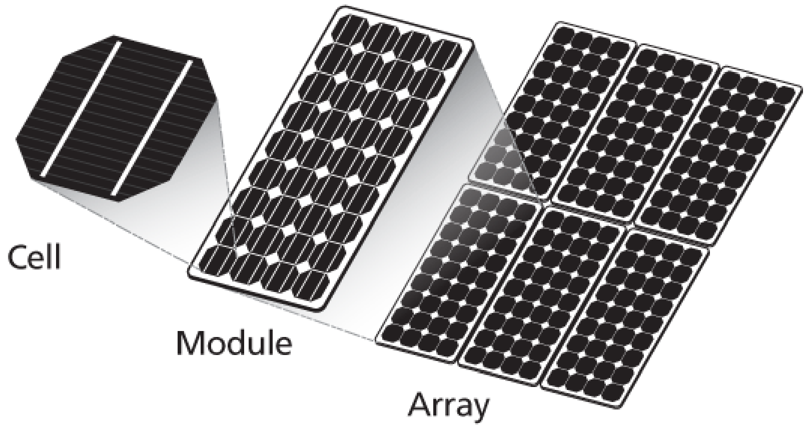


Figure 2.12 Formation of Array from Cells and then Modules

Germanium, Silicon, Gallium Arsenide, Indium Arsenide and Cadmium Arsenide are usually used for production of solar cells. Different materials have different properties and efficiencies. Silicon is mostly adopted for development of solar panels. It is cheap and abundant in nature. Efficiency of solar panels is the biggest issue to deal with. Only a small fraction of falling light can be converted into electricity.

2.5 Solar Radiation

Light is the form of energy. Sun is the biggest source of light. Light is constantly emitted by sun but due to relative motion of Earth sunlight is obtained in day time only if weather conditions are fine. Sunlight is the part of solar radiant electromagnetic energy. These solar radiations have three bands which are Ultraviolet, Infrared and Visible. Ultraviolet band contains some dangerous waves which are hazardous to life. These rays are filtered and are stopped from reaching Earth by the help Ozone layer present in atmosphere. Sun radiations contain almost 49.4% infrared radiations having wavelength 700 nm to more than 1 mm, 42.3% visible radiations having wavelength from 400 nm to 700 nm and 8% ultraviolet radiations having wavelength from 100 nm to 400 nm. [31]

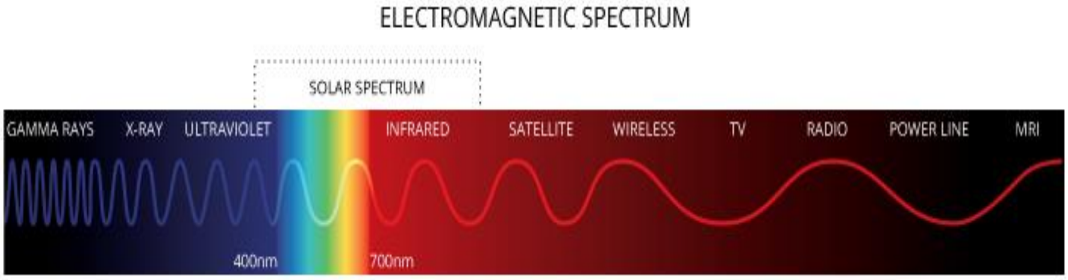


Figure 2.13 Illustration of Electromagnetic spectrum

2.6 Solar Irradiance

Different parts of the world receive different values of solar radiations throughout the year. Calculations show that places near Equator has more solar irradiance than Northern and Southern hemisphere. Solar irradiance is the count of solar radiant flux falling on specific area and it has unit of Watt per meter square (W/m^2)[31]. Areas with more solar irradiance value are more feasible for installation of solar energy system. Various factors are responsible for different values of solar irradiance across the world. Height of specific place is compared with sea level and it varies from place to place. Places with higher elevation are comparatively closer to sun than those places which are with less elevation.

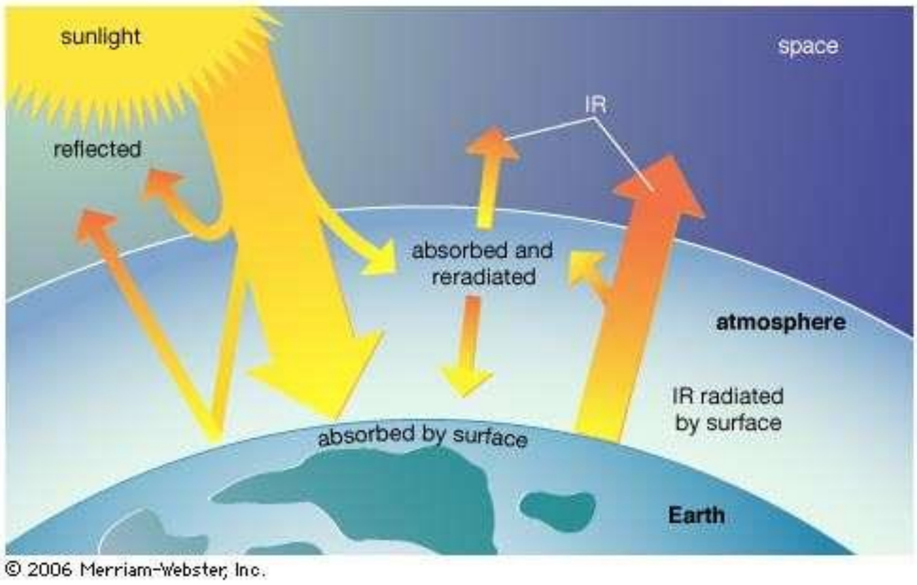


Figure 2. 14 Types of solar irradiance

2.7 Summary

In this chapter literature review is done. All related studies are discussed and factors which effect solar system performance are elaborated. Different studies are discussed for the sizing of renewable energy systems. The case studies have been reviewed for the research work that ensures the utilization of the software for different purposes. There are different researchers that have been carried out but some of them are discussed in these case studies using different tools. In addition to that, the consideration is also made for that installed solar systems and the factors that affect the system's performance. Mostly studies are done with a single sizing software compared with installed system. In this study is same system is designed with three different tools and then compared with actual output of solar system to find out optimum tool for sizing and possible reasons of deviations in output.

References

[11] C.P. Kandasamy, P. Prabu ,Solar Potential Assessment Using PVSYST Software , (ICGCE) 2014.

[12] P G Nikhil, Solar Photovoltaic (PV) System Sizing, 2015 International Conference on Control, Communication & Computing India (ICCC)

[13] L. N. Khairlybayeva, "Viability Of On-Grid Residential PV Systems In Southwest Kazakhstan. Case: Mangystau Region", 2020. Available: https://www.academia.edu/34082582/VIABILITY_OF_ON_GRID_RESIDENTIAL_PV_SYSTEMS_IN_SOUTHWEST_KAZAKHSTAN_CASE_MANGYSTAU_REGION.

[14] Pradhan Arjyadhara,Ali S.M,Jena Chitralekha., "Analysis of solar PV cell performance with changing irradiance and temperature," International Journal Of Engineering And Computer Science, 2013, vol. 2, pp. 214-220, Jan 2013.

[15] Mohammad I. Hossain "Numerical analysis of the temperature effects on single junction solar cells efficiencies" Solar Energy Materials & Solar Cells vol. 10, pp. 78-85, 2015.

[16] Temitope M. John, A tutorial on the development of a Smart Calculator to determine the Installed Solar requirements for Households and Small businesses, 2018 IEEE PES/IAS PowerAfrica

[17] Anula Khare ,Optimal sizing of a grid integrated solar photovoltaic system IET Renew. Power Gener., 2015, Vol. 8, Iss. 1, pp. 67–75

[18] J. Ramoliya, "Performance Evaluation of Grid-connected Solar Photovoltaic plant using PVSYST Software", JETIR, vol. 2, no. 2, pp. 372-378, 2019. Available: http://www.jetir.org/papers/JETIR1502036.pdf.

[19] P G Nikhil, D Subhakar, Supinder Jeet Singh. "Solar photovoltaic (PV) system sizing: Considerations from name plate specifications", 2015 International Conference on Control Communication & Computing India (ICCC), 2015.

[20] Temitope M. John, Samuel T. Wara. "A Tutorial on the Development of a Smart Calculator to Determine the Installed Solar Requirements for Households and Small Businesses", 2018 IEEE PES/IAS PowerAfrica, 2018

[21] Khare, Anula, and Saroj Rangnekar. "Optimal sizing of a grid integrated solar photovoltaic system", IET Renewable Power Generation, 2014.

[22] Pradhan Arjyadhara,Ali S.M,Jena Chitralekha., "Analysis of solar PV cell performance with changing irradiance and temperature," International Journal Of Engineering And Computer Science, 2013, vol. 2, pp. 214-220, Jan 2013.

[23] Kane, A.; Verma, V., "Characterization of PV cellenvironmental factors consideration," Power, Energy and Control (ICPEC), 2013 International Conference on , vol., no., pp.26,29, 6-8 Feb. 2013.

[24] 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

[25] Bhalachandra. V. Chikate, " Factors affecting the performance of solar cell"- International journal of computer applications-,2015

[26] Furkan Dincer, Mehmet Emitmeral, "Critical factors that affecting the efficiency of solar cells"- smart grid and renewable energy,2010

[27] S. Mekhilef, R. Saidur, and M. Kamalisarvestani, "Effect of dust, humidity and air velocity on efficiency of photovoltaic cells," Renew. Sustain. Energy Rev., vol. 16, no. 5, pp. 2920–2925, 2012.

[28] B. Ragavi, Determination of step angle for tracking the sun position of any location , 4th International Conference on Electrical Energy Systems (ICEES),2018.

[29] D.W. van der Meer, J. Widen, J. Munkhammar, Review on probabilistic forecasting of photovoltaic power production and electricity consumption, Renew. Sustain. Energy Rev. 81 (2018) 1484–1512

[30] M. Mendonça, Feed-in Tariffs: Accelerating the Deployment of Renewable Energy, Routledge, 2010.

Chapter 3

Methodology

Various software and online tools are available to analyze and evaluate the performance of solar photovoltaic system. We just need some basic parameters like location where system is to be installed, capacity of system (DC rating of system), rating of inverter, manufacturer of inverter, backup for dark days, battery ratings etc. The system designing is carried out using different tools and software. The basis of the designing is selection of a particular site and sizing of the system according to the load. The software also takes into account the geographical location as well as solar radiance data is the main parameter of the system designing [31]. The comparison has also been carried out among the results of different software to confirm the authenticity of the designed system.

3.1 Sizing Parameters

The sizing parameter is an important consideration for the efficient working of solar system at all the levels of residential commercial and industrial scales. For this purpose, first of all the calculations are made for the load in amperes and power, and duration for which the load will operate throughout the day. Load calculations are based on seasonal variations such as Air Conditioners or heaters which operate in summer and winter seasons, respectively. However, the system designing contains requirement of peak load conditions to meet entire load if operated. After the consideration of load and its duration of operation, the sizing is carried out for the inverter and solar PV panels. It also takes into account the area available for the installation of solar PV panels and the cost associated with the system designing. On the basis of costing or availability of the budget, the options are created for the system to be installed [32]. An example is inclusion or exclusion of battery system which may increase the cost of PV system.

Once the load is calculated successfully solar system sizing come into play, different softwares are available to perform this job, these softwares predict solar system output at specific location for the whole year, weather conditions plays vital role in solar system so each software use weather data provided by NASA which mainly has temperature, humidity, air speed and solar irradiance falling measurement for the whole year[33].

3.2 System Designing with RETScreen Expert

RETScreen is a tool designed by Canadian Government. It uses weather data provided by NASA. In this version users are able to save and print in professional versions, without these functions this tool can also be used without any subscription or activation charges. The energy generation estimation can be done with weather data selection of that specific place where the system is needed to be installed.

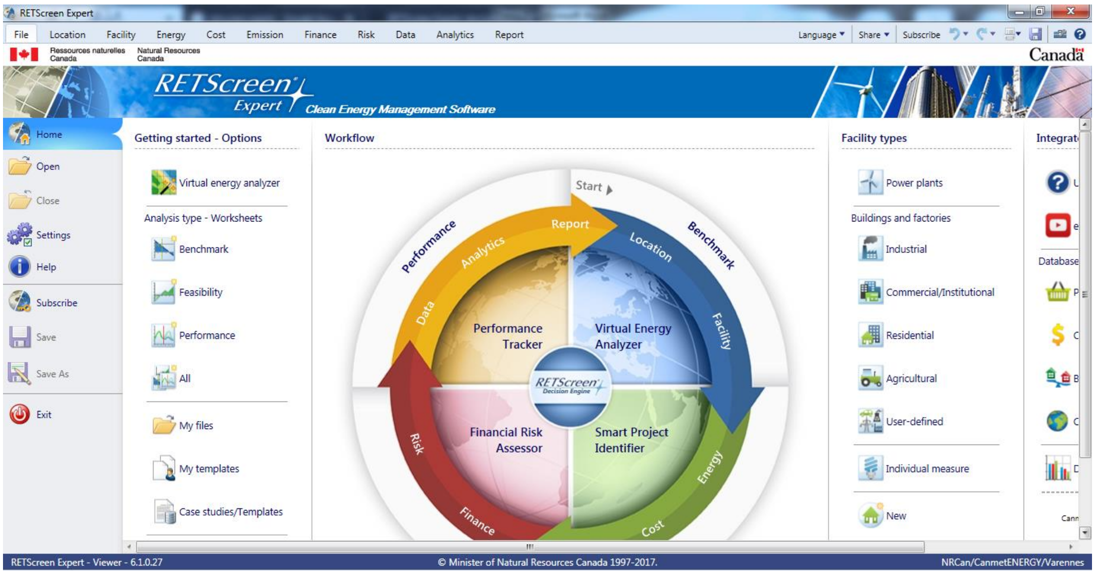
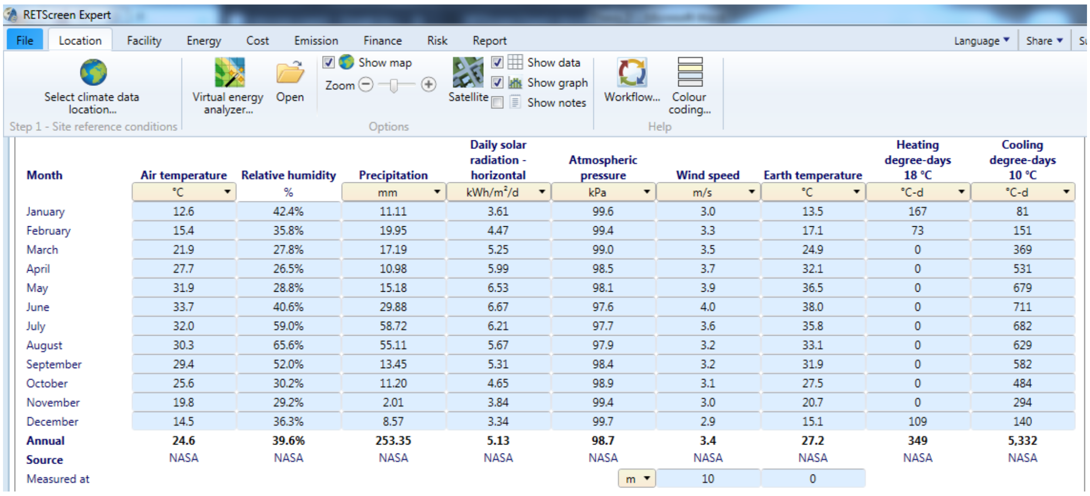


Figure 3.1 Main panel board of RETScreen

3.2.1 Site Selection

First of all, location is selected where system performance is needed to be analyzed virtually to draw any conclusion about feasibility of project for this location. Choose option “Virtual Energy Analyzer” first and then a window appears containing information of system weather data, when location where user want to analyze the performance of system is chosen following window appears containing important information about weather properties and location of that place for example for our case location is set as "Bahawalpur, Pakistan. Latitude 29.4" , Longitude 71.7".

When location is chosen by the user weather data is automatically imported from **NASA** and all prerecorded weather properties of that location for whole year are displayed in figure 3.2. This data includes information about Air temperature, Relative Humidity, Daily solar Irradiance at horizontal plane, wind speed etc. These factors plays very crucial role in generation of solar power. These values are provided by NASA and values of solar irradiance are recorded for horizontal plane which fluctuate throughout the year hence generation also changes according to irradiance.



Month	Air temperature (°C)	Relative humidity (%)	Precipitation (mm)	Daily solar radiation - horizontal (kWh/m²/d)	Atmospheric pressure (kPa)	Wind speed (m/s)	Earth temperature (°C)	Heating degree-days 18 °C (°C-d)	Cooling degree-days 10 °C (°C-d)
January	12.6	42.4%	11.11	3.61	99.6	3.0	13.5	167	81
February	15.4	35.8%	19.95	4.47	99.4	3.3	17.1	73	151
March	21.9	27.8%	17.19	5.25	99.0	3.5	24.9	0	369
April	27.7	26.5%	10.98	5.99	98.5	3.7	32.1	0	531
May	31.9	28.8%	15.18	6.53	98.1	3.9	36.5	0	679
June	33.7	40.6%	29.88	6.67	97.6	4.0	38.0	0	711
July	32.0	59.0%	58.72	6.21	97.7	3.6	35.8	0	682
August	30.3	65.6%	55.11	5.67	97.9	3.2	33.1	0	629
September	29.4	52.0%	13.45	5.31	98.4	3.2	31.9	0	582
October	25.6	30.2%	11.20	4.65	98.9	3.1	27.5	0	484
November	19.8	29.2%	2.01	3.84	99.4	3.0	20.7	0	294
December	14.5	36.3%	8.57	3.34	99.7	2.9	15.1	109	140
Annual	**24.6**	**39.6%**	**253.35**	**5.13**	**98.7**	**3.4**	**27.2**	**349**	**5,332**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 3.2 Data selection for whole year containing different parameters

After selecting location of project setting parameters of solar systems are needed to be set. First of all, DC ratings of solar project are set. In this project DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 15% and Tilt angle is varied from 0° to 60°.

3.3 System designing with PVsyst

In this study system of 100 MW DC rating is designed and weather data for Bahawalpur is imported with coordinates as shown in figure 3.3

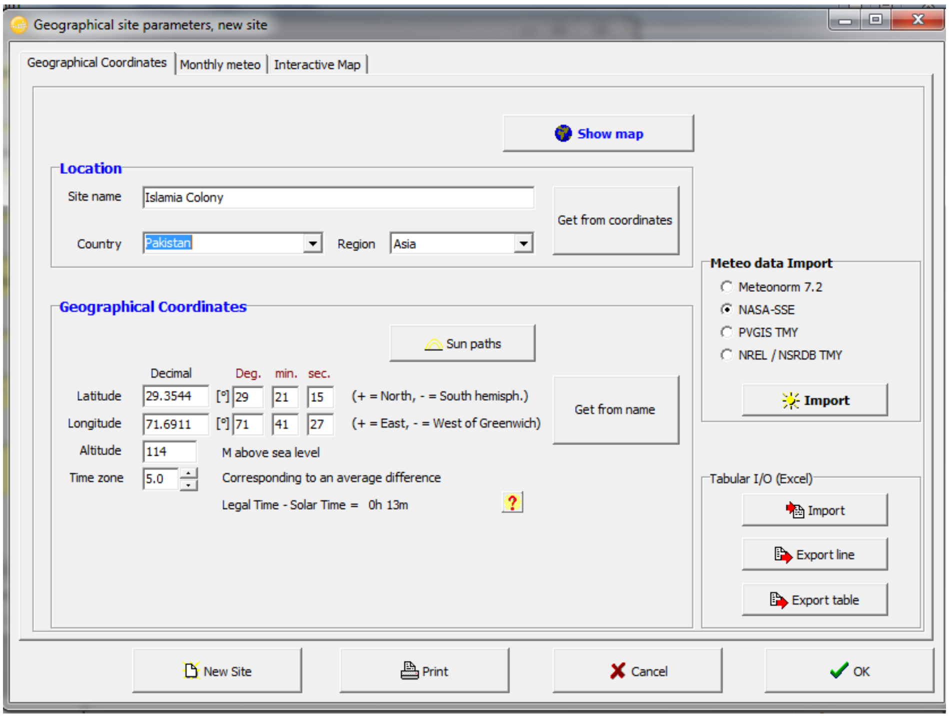


Figure 3.3 Acquirement of parameters of PVSyst for Islamia Colony, Pakistan

When weather data of desired is successfully imported following details of weather data are obtained including horizontal global irradiation, Horizontal diffuse irradiation, temperature and wind speed respectively as shown in figure 3.4

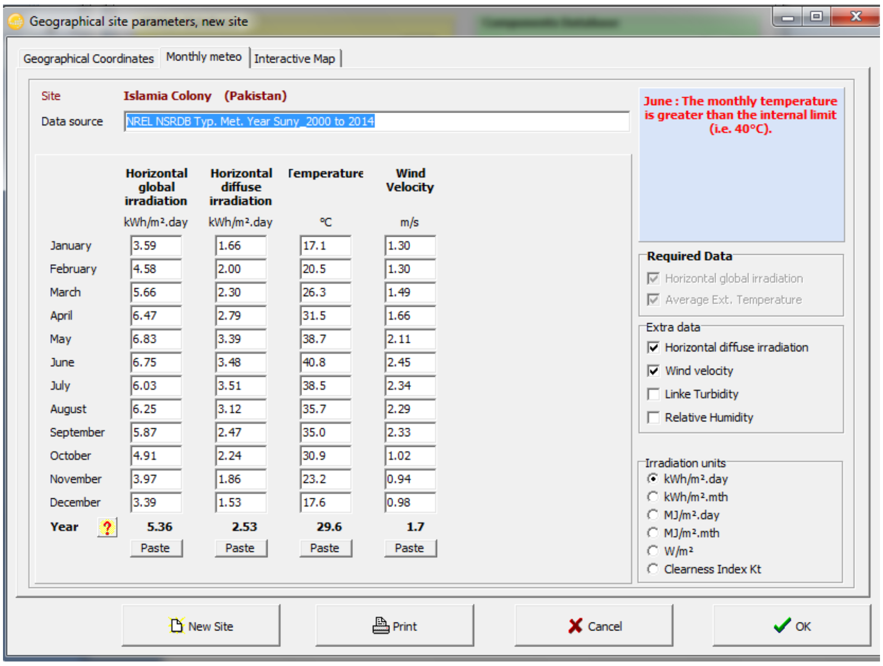


Figure 3. 4 Irradiance values of parameters of PVSyst from 2000 to 2014

3.3.1 System specifications

Once the weather data of desirable location is imported specific parameters of system are set with user defined values, these parameters includes Nominal Power rating of the system set to be 100 MW. Tilt angle of solar panel is varied from 0^o to 60^o and output is compared at different tilt angles.

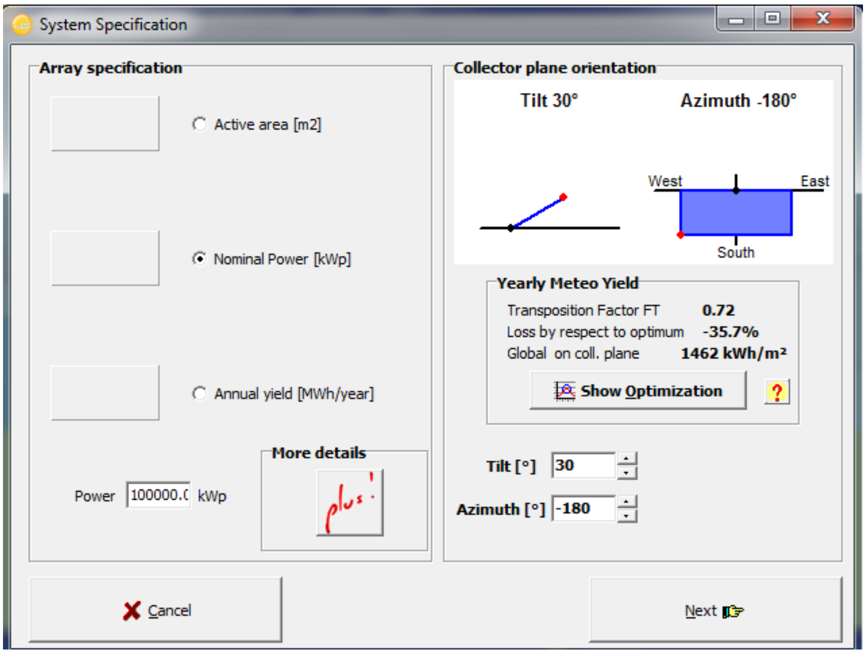


Figure 3 5 PVSyst Solar Panel Tilt setting

Technology of panels used i.e. in proposed case is Polycrystalline cell. Mounting deposition is selected as Ground based and ventilating property is selected as ventilated as shown in figure 3.6

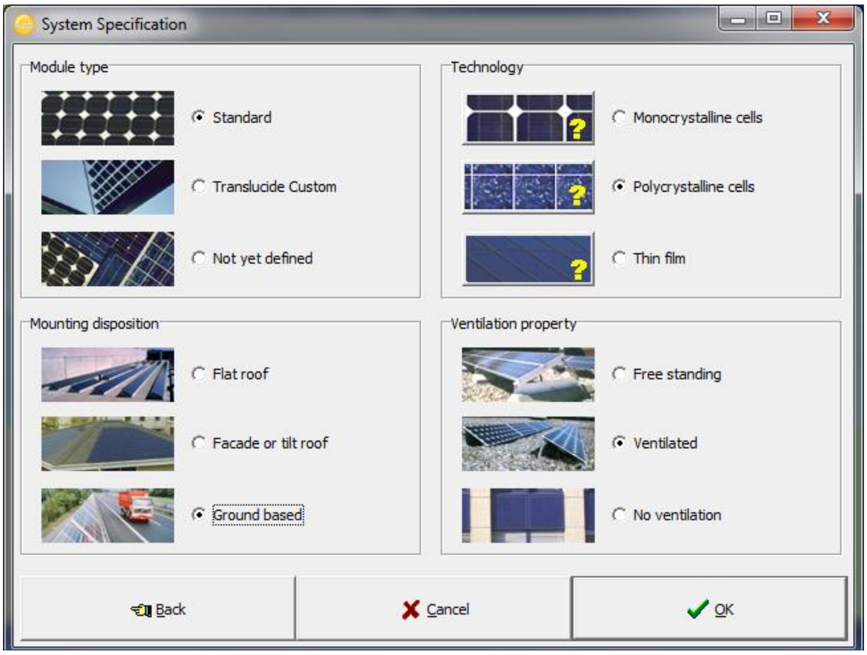


Figure 3.6 PVSyst Solar Panel Properties Selection

3.4 System designing with PVWatts

PVWatts is an online tool to analyze generation and estimate cost of energy for grid connected solar photovoltaic systems. It is easily available online and any one from any part of the world can estimate solar system performance, one just need to have an internet access and does not need any license or subscription to use this tool. This tool has been made easy to use and is developed by a laboratory of US Department of Energy.

First of all URL given below was accessed

https://pvwatts.nrel.gov/

Once the URL was loaded location where the performance of system is to be analyzed is given for this case location given as Bahawalpur.

Location and Station Identification

Requested Location	bahawalpur
Weather Data Source	Lat, Lon: 29.35, 71.65 3.2 mi
Latitude	29.35° N
Longitude	71.65° E

Figure 3 7 Data and parameters using PVWatts

Once the location is selected System specifications like Rating of System, Type of solar Panels used in this case is Standard, Array type used is fixed (open rack) System losses are 14.02% by default, Inverter Efficiency is 96% by default tilt angle is varied from 0^o to 60^o.

3.5 Chapter Summary

In this chapter methodology following which this research study is carried out, is explained. We have target site of Quaid-e-Azam Solar Park, with the defined coordinates. System is designed keeping all parameters of sizing same for each system designing. Types of panels, tilt angle of panels, rated DC power of system, location, losses, etc. all parameters are kept same for system designing with RETScreen, PVSyst and PVWatts.

References

[31] C.P. Kandasamy, P. Prabu ,Solar Potential Assessment Using PVSYST Software , (ICGCE) 2014.

[32] L. N. Khairlybayeva, "Viability Of On-Grid Residential PV Systems In Southwest Kazakhstan. Case: Mangystau Region", 2020. Available: https://www.academia.edu/34082582/VIABILITY_OF_ON_GRID_RESIDENTIAL_PV_SYSTEMS_IN_SOUTHWEST_KAZAKHSTAN_CASE_MANGYSTAU_REGION.

[33] J. Ramoliya, "Performance Evaluation of Grid-connected Solar Photovoltaic plant using PVSYST Software", JETIR, vol. 2, no. 2, pp. 372-378, 2019. Available: http://www.jetir.org/papers/JETIR1502036.pdf.

[34] B. Ragavi, Determination of step angle for tracking the sun position of any location , 4th International Conference on Electrical Energy Systems (ICEES),2018.

[35] Quaid-e-Azam Solar Power, Quaid-e-Azam Solar Power (Pvt.) Limited, Pakistan (2020).

Chapter 4
Results

Solar sizing is an important parameter, many applications are made to predict and estimate performance of solar system for given location. Weather data influence the performance of solar system significantly that is why it is important to record weather parameters precisely [36]. In this study solar system of DC Rating 100 MW located at Bahawalpur, Punjab, Pakistan is designed with three different tools which are RETScreen, PVsyst and PVWatts. Most softwares use weather data provided by NASA. That is why it is important to compare vital parameters of weather data used by software should be similar with the actual data. For this purpose and to check validity and prediction capability of different softwares this study is carried out. In this study these designed systems are compared with system installed at Quaid-e-Azam solar power plant near Bahawalpur, Punjab, Pakistan having DC Rating 100 MW. Recorded values for different parameters of Quaid-e-Azam solar park are given in table 4.1 and onwards. Irradiance recorded for year 2018 at Quaid-e-Azam Solar Park Bahawalpur, Punjab, Pakistan is given below in table

Table 4.1 Irradiance Data for different months of 2018 for Quaid-e-Azam Solar Park, Bahawalpur, Pakistan

Month	Irradiance
Jan	5.03
Feb	5.67
Mar	6.78
Apr	6.67
May	6.27
Jun	5.84
Jul	5.89
Aug	6.15
Sep	6.48
Oct	6.01
Nov	4.87
Dec	5.05

Humidity recorded for year 2018 at Quaid-e-Azam Solar Park Bahawalpur, Punjab, Pakistan is given below in table 4.2

Table 4.2 Humidity Data for different months of 2018 for Quaid-e-Azam Solar Park, Bahawalpur, Pakistan

Month	% Humidity
Jan	60.15
Feb	55.17
Mar	49.25
Apr	35.74
May	31.67
Jun	45.70
Jul	57.56
Aug	57.75
Sep	55.93
Oct	49.20
Nov	58.33
Dec	65.23

Wind speed recorded for year 2018 at Quaid-e-Azam Solar Park Bahawalpur, Punjab, Pakistan is given below in table 4.3

Table 4.3 Wind speed Data for different months of 2018 for Quaid-e-Azam Solar Park, Bahawalpur, Pakistan

Month	Avg. wind speed
Jan	2.17
Feb	2.68
Mar	2.92
Apr	3.32
May	3.37
Jun	3.88
Jul	3.64
Aug	3.77

Sep	3.46
Oct	2.59
Nov	2.26
Dec	2.23

Average ambient temperature recorded for year 2018 at Quaid-e-Azam Solar Park Bahawalpur, Punjab, Pakistan is given below in table 4.4

Table 4.4 Average Ambient Temperature Data for different months of 2018 for Quaid-e-Azam Solar Park, Bahawalpur, Pakistan

Month	Avg. Ambient Temperature
Jan	11.75
Feb	16.29
Mar	23.44
Apr	30.18
May	33.50
Jun	35.33
Jul	33.98
Aug	32.84
Sep	31.09
Oct	25.84
Nov	19.71
Dec	12.63

Generation recorded for year 2018 at Quaid-e-Azam Solar Park Bahawalpur, Punjab, Pakistan is given below in table 4.5

Table 4.5 Generation Data for different months of 2018 for Quaid-e-Azam Solar Park, Bahawalpur, Pakistan

Generation of QASP in 2018	
Jan	12252
Feb	12568.6

Mar	16179.6
Apr	15003.6
May	14214
Jun	13128
Jul	13942.8
Aug	14630.4
Sep	14926.8
Oct	14334
Nov	11253.6
Dec	12180

4.1 RETScreen Designed System Outputs

System is designed with RETScreen keeping all the parameters same as that of Quaid-e-Azam Solar Park. System output is taken on different angles (from 0o to 60o) with 15o increment and the output obtained from systems designed with RETScreen are shown from figure 4.1 to figure 4.5 respectively.

4.1.1 RETScreen designed system output with 0o tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 0^{o}. Output of the designed system with described parameters in given in figure 4.1

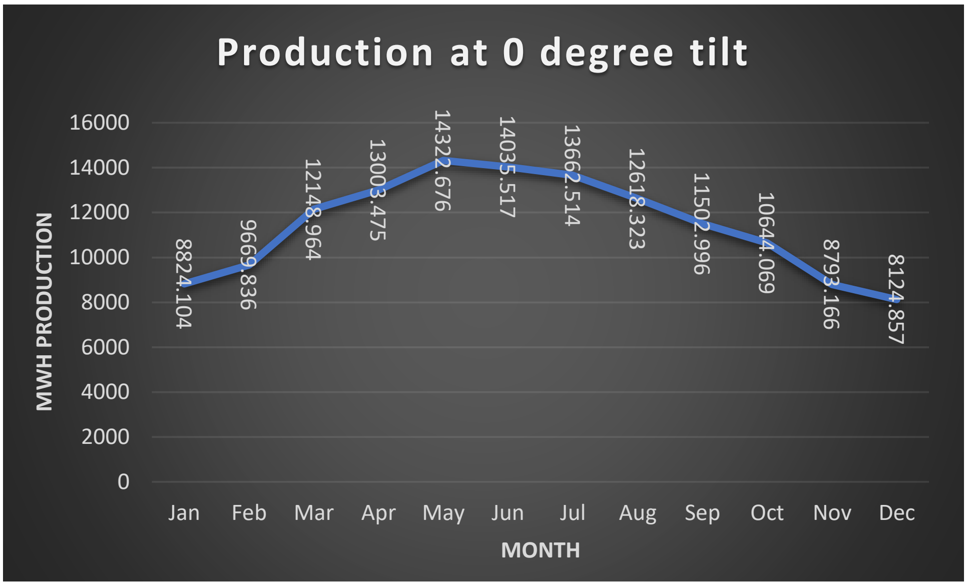


Figure 4. 1 Output of RETScreen designed system at 0º Slope and 0º Azimuth

4.1.2 RETScreen designed system output with 15º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 15˚. Output of the designed system with described parameters in given in figure 4.2

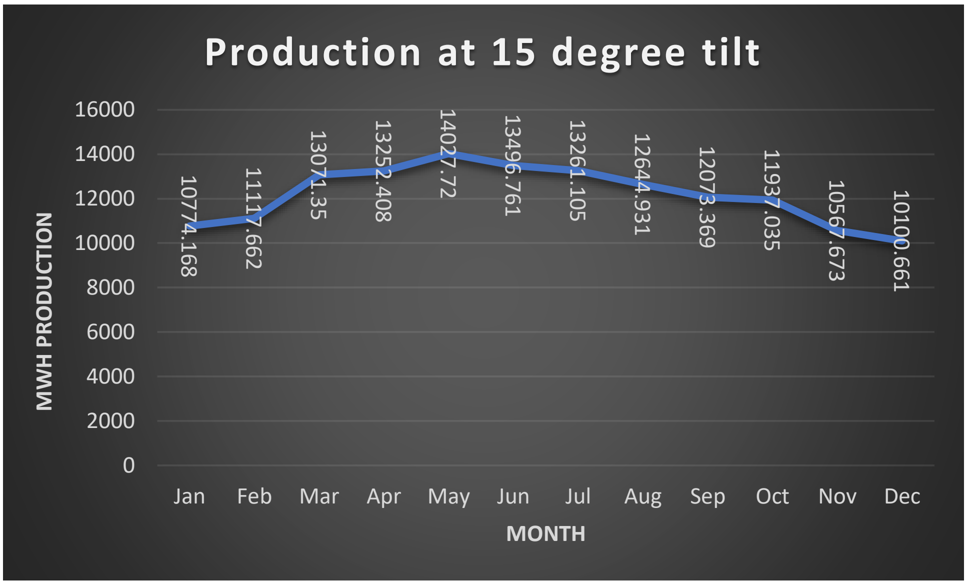


Figure 4. 2 Output of RETScreen designed system at 15º Slope and 0º Azimuth

4.1.3 RETScreen designed system output with 30° tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 30°. Output of the designed system with described parameters in given in figure 4.3

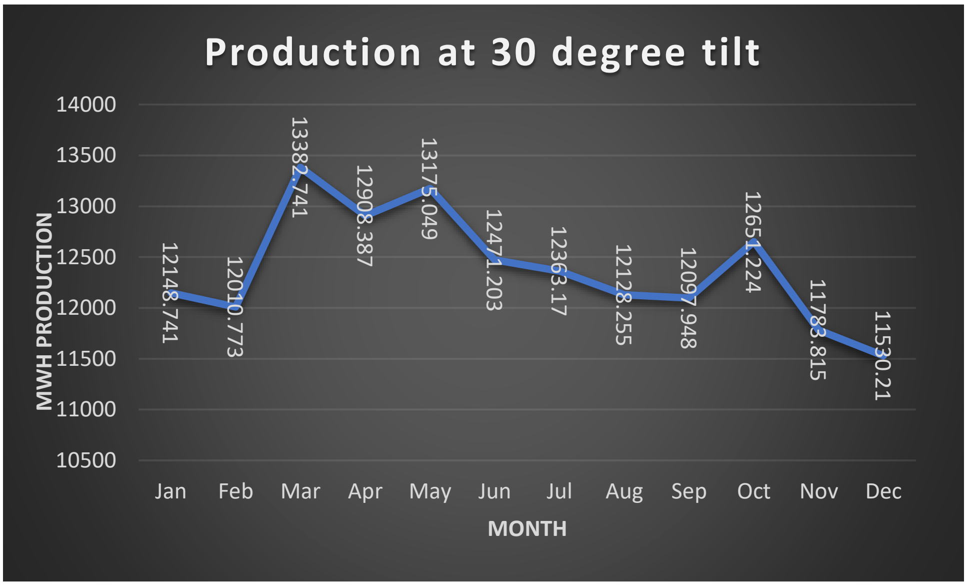


Figure 4. 3 Output of RETScreen designed system at 30° Slope and 0° Azimuth

4.1.4 RETScreen designed system output with 45° tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 45°. Output of the designed system with described parameters in given in figure 4.4

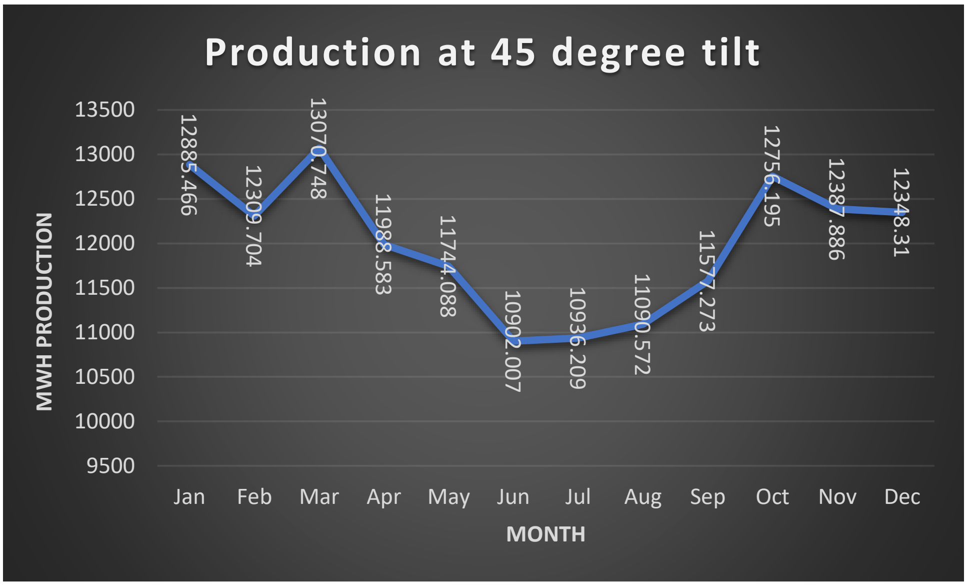


Figure 4. 4 Output of RETScreen designed system at 45º Slope and 0º Azimuth

4.1.5 RETScreen designed system output with 60º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 60^{o}. Output of the designed system with described parameters in given in figure 4.5

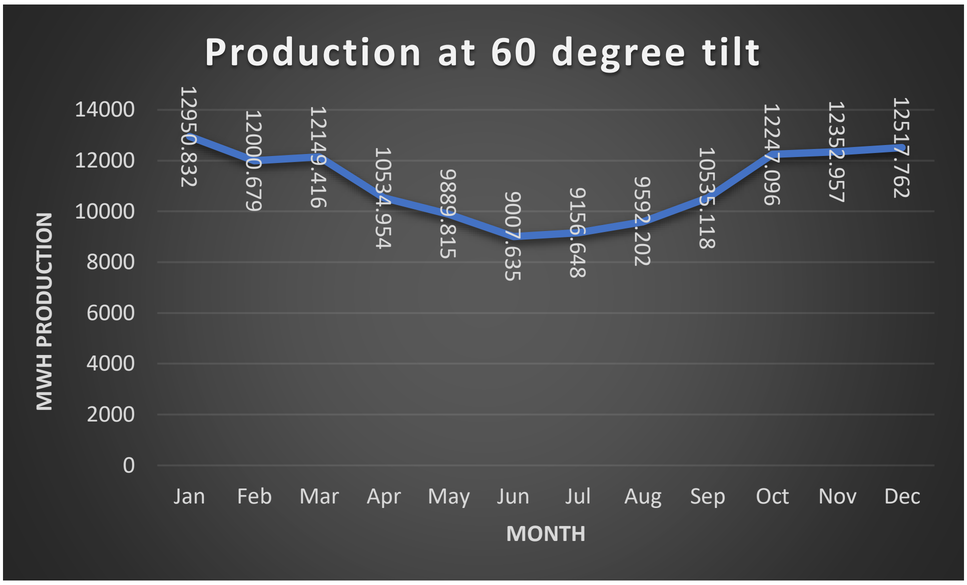


Figure 4. 5 Output of RETScreen designed system at 60º Slope and 0º Azimuth

4.2 PVSyst Designed System Outputs

System is designed with PVSysyst keeping all the parameters same as that of Quaid-e-Azam Solar Park. System output is taken on different angles (from 0° to 60°) with 15o increment and the output obtained from systems designed with PVSyst are shown from figure 4.6 to figure 4.10 respectively.

4.2.1 PVSyst designed system output with 0° tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 0°. Output of the designed system with described parameters in given in figure 4.6

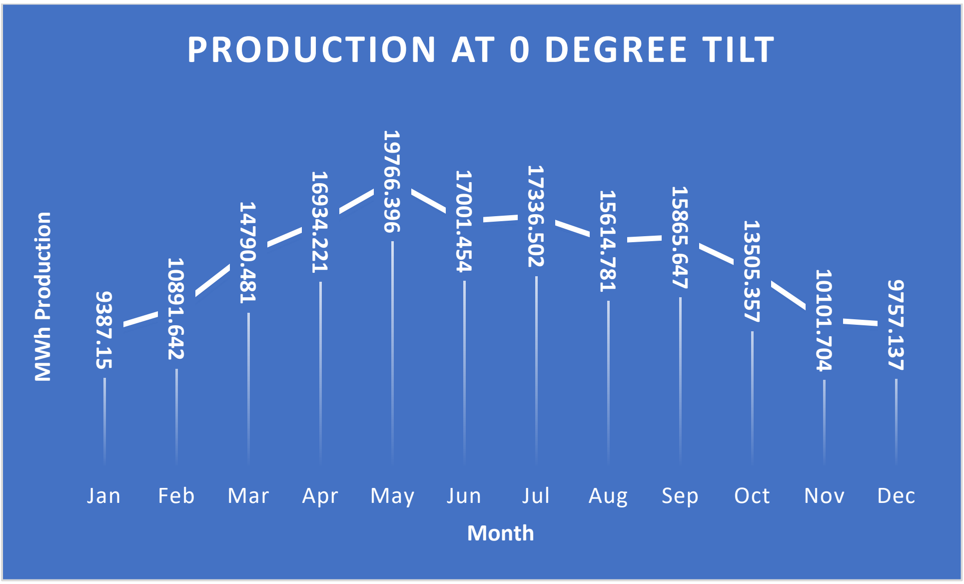


Figure 4. 6 PVSyst Energy Output having 0° tilt and 0° Azimuth

4.2.2 PVSyst designed system output with 15° tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 15°. Output of the designed system with described parameters in given in figure 4.7

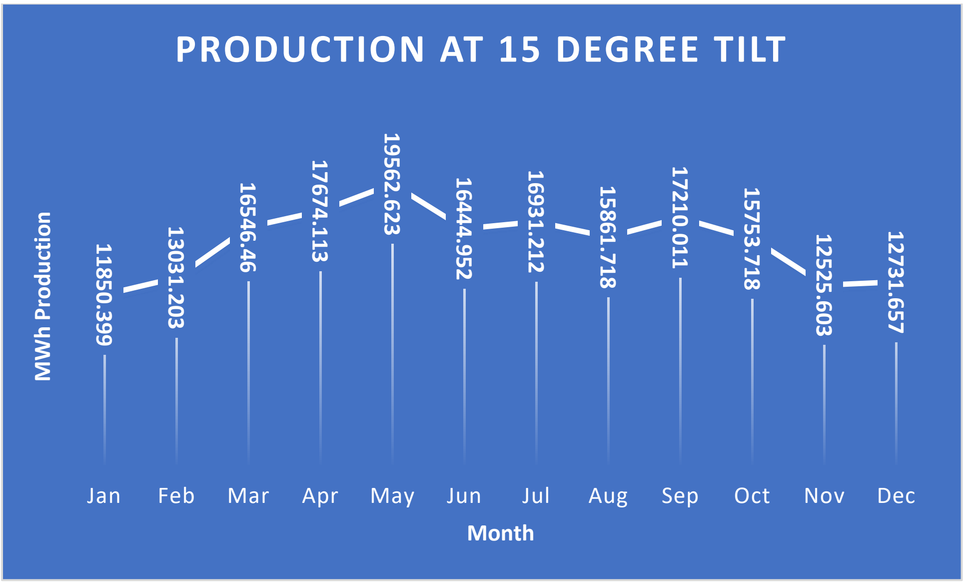


Figure 4. 7 PVSyst Energy Output having 15° tilt and 0° Azimuth

4.2.3 PVSyst designed system output with 30º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 30º. Output of the designed system with described parameters in given in figure 4.8

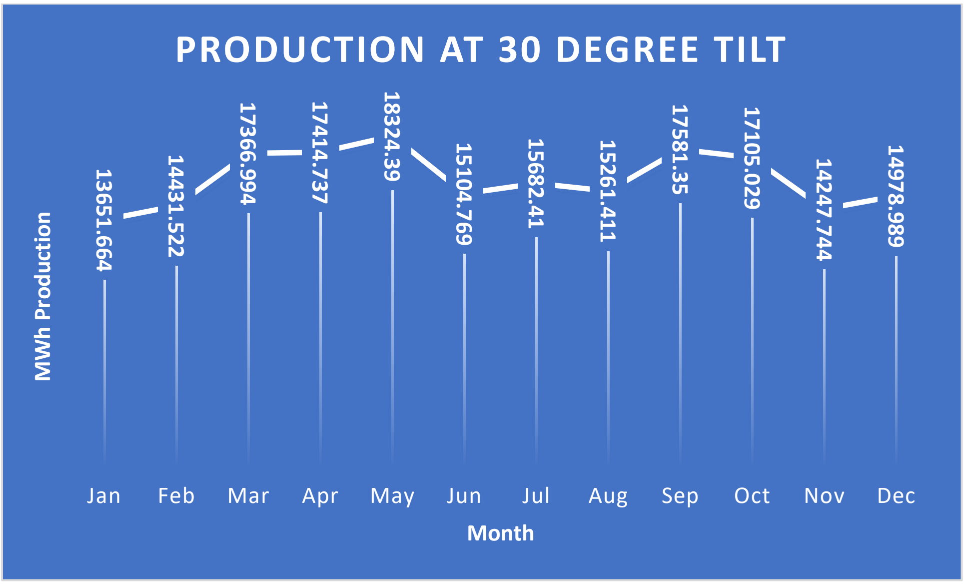


Figure 4. 8 PVSyst Energy Output having 30° tilt and 0° Azimuth

4.2.4 PVSyst designed system output with 45º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 0º. Output of the designed system with described parameters in given in figure 4.9

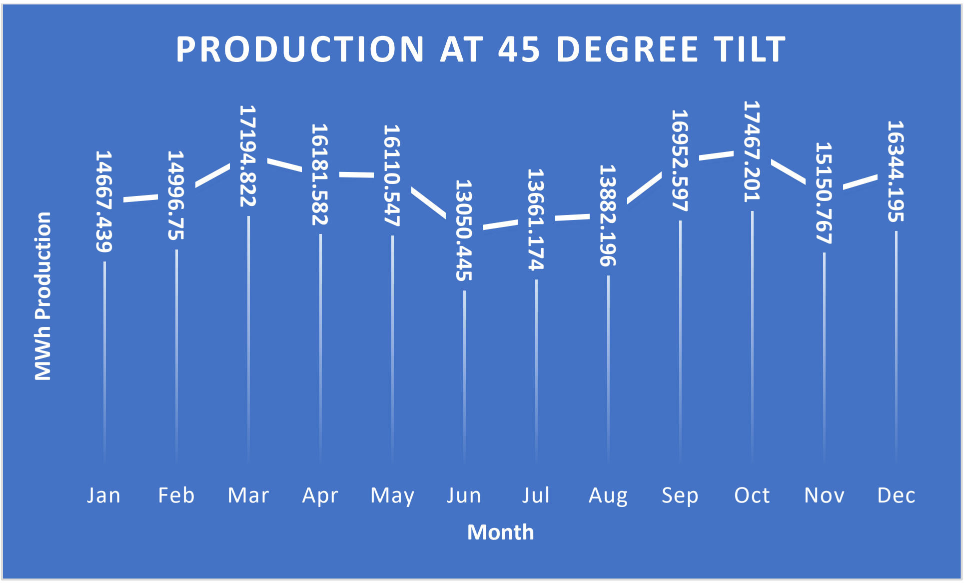


Figure 4. 9 PVSyst Energy Output having 45° tilt and 0° Azimuth

4.2.5 PVSyst designed system output with 60º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 60º. Output of the designed system with described parameters in given in figure 4.10

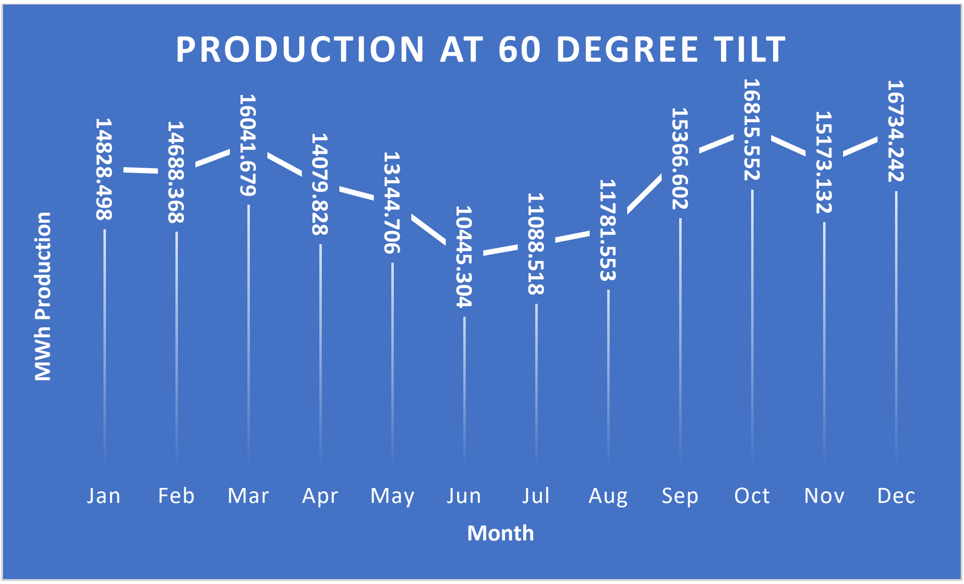


Figure 4. 10 PVSyst Energy Output having 60° tilt and 0° Azimuth

4.3 PVWatts Designed System Outputs

System is designed with PVWatts keeping all the parameters same as that of Quaid-e-Azam Solar Park. System output is taken on different angles (from 0o to 60o) with 15o increment and the output obtained from systems designed with PVWatts are shown from figure 4.6 to figure 4.10 respectively.

4.3.1 PVWatts designed system output with 0° tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 0°. Output of the designed system with described parameters in given in figure 4.11

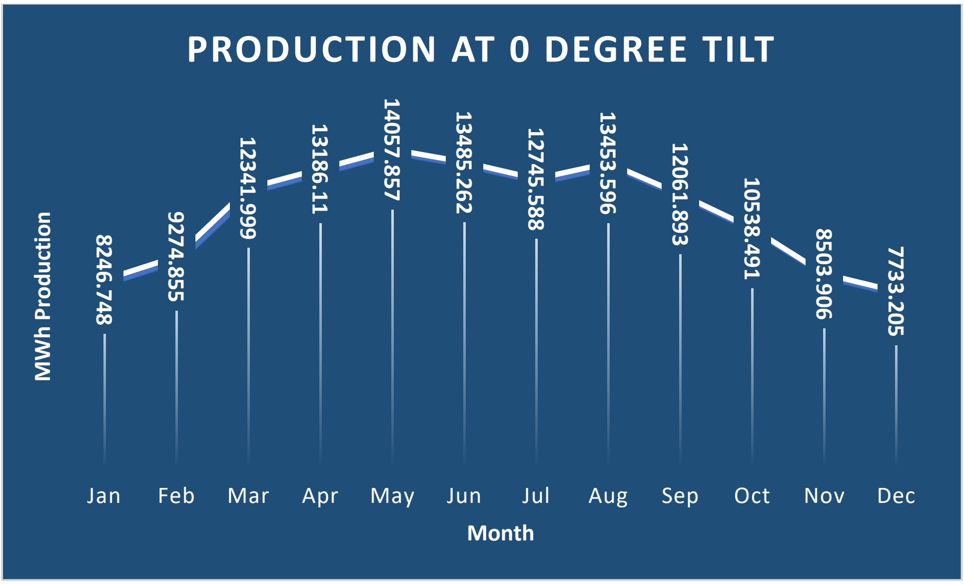


Figure 4. 11 Input data and Energy Output having 0° tilt and 0° Azimuth

4.3.2 PVWatts designed system output with 15º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 15º. Output of the designed system with described parameters in given in figure 4.12

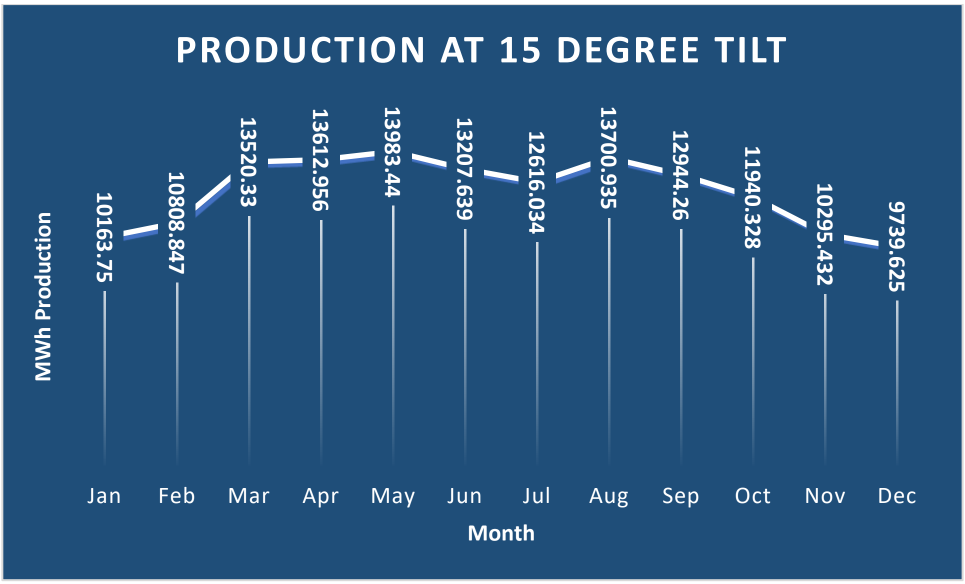


Figure 4. 12 PVWatts Energy Output having 15° tilt and 0° Azimuth

4.3.3 PVWatts designed system output with 30º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 30º. Output of the designed system with described parameters in given in figure 4.13

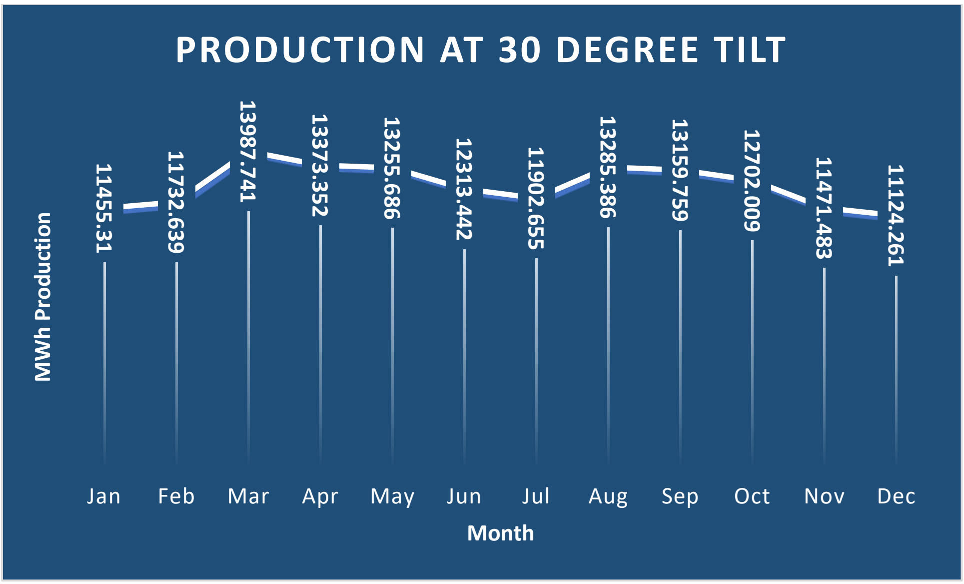


Figure 4. 13 PVWatts Energy Output having 30° tilt and 0° Azimuth

4.3.4 PVWatts designed system output with 45º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 45º. Output of the designed system with described parameters in given in figure 4.14

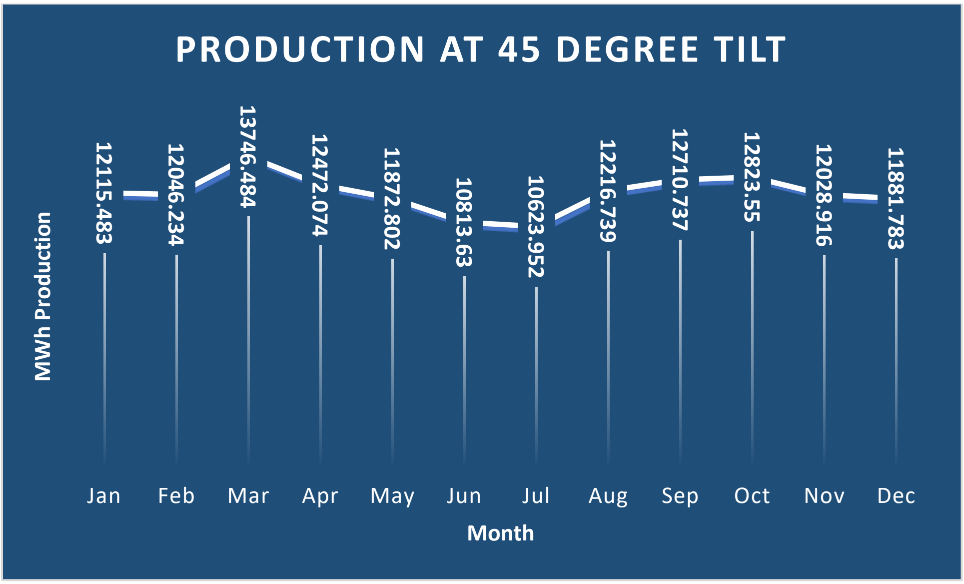


Figure 4. 14 PVWatts Energy Output having 45° tilt and 0° Azimuth

4.3.5 PVWatts designed system output with 60º tilt angle

System location is set as Bahawalpur. DC ratings are set to be 100 MW DC. Type of module used is selected as Polycrystalline. Inverter efficiency is kept 95%. Miscellaneous losses are set as 10% and Tilt angle is set as 60º. Output of the designed system with described parameters in given in figure 4.15

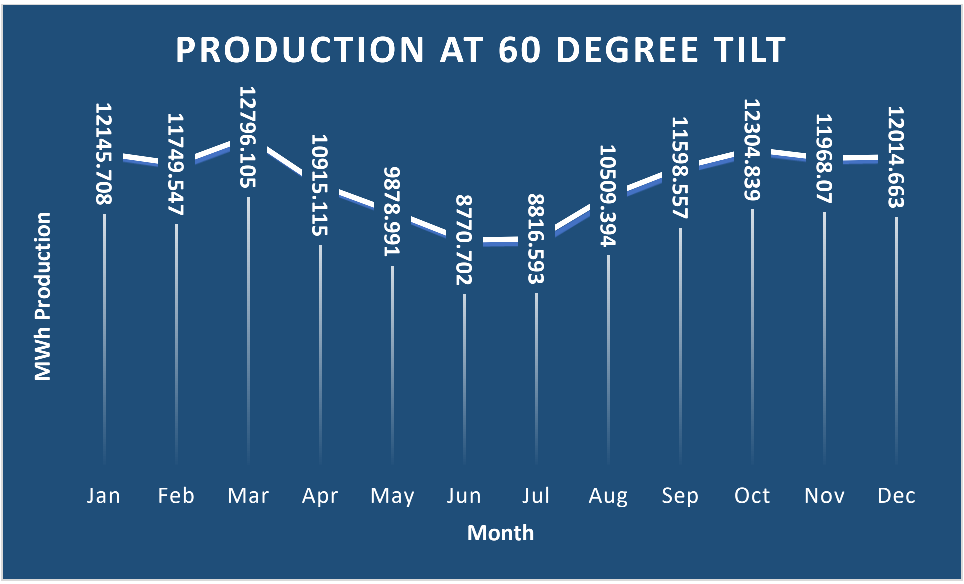


Figure 4. 15 PVWatts Energy Output having 60° tilt and 0° Azimuth

4.4 Chapter Summary

In this chapter all results of designed systems are expressed with recorded system statics of Quaid-e-Azam Solar Park. All the parameters of sizing were kept same as Quaid-e-Azam solar Park parameters for all the designed system but the results obtained are significantly different and PVWatts results found to be more accurate and close to recorded values, RETScreen was 2nd close to recorded values while PVSyst has significant difference with the recorded values of solar generation system. Pictorial comparison of designed systems with installed system is shown in figure 4.16.

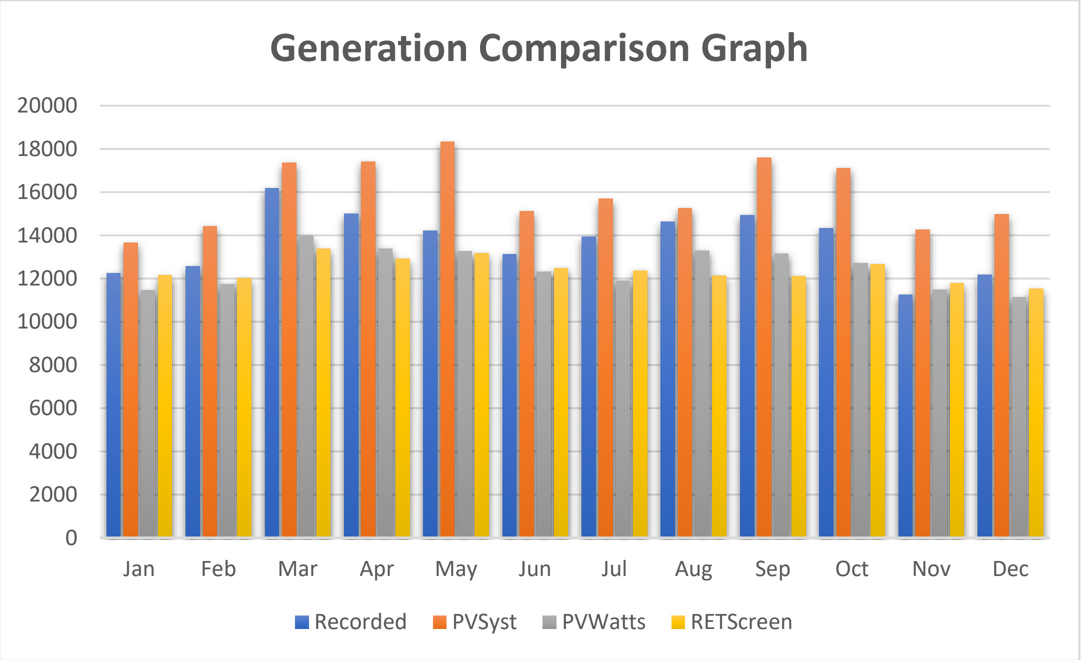


Figure 4. 16 Comparison of predicted generation and obtained generation

References

[36] C.P. Kandasamy, P. Prabu ,Solar Potential Assessment Using PVSYST Software , (ICGCE) 2014.

[37] P G Nikhil, Solar Photovoltaic (PV) System Sizing, 2015 International Conference on Control, Communication & Computing India (ICCC)

[38] L. N. Khairlybayeva, "Viability Of On-Grid Residential PV Systems In Southwest Kazakhstan. Case: Mangystau Region", 2020. Available: https://www.academia.edu/34082582/VIABILITY_OF_ON_GRID_RESIDENTIAL_PV_SYSTEMS_IN_SOUTHWEST_KAZAKHSTAN_CASE_MANGYSTAU_REGION.

[39] J. Ramoliya, "Performance Evaluation of Grid-connected Solar Photovoltaic plant using PVSYST Software", JETIR, vol. 2, no. 2, pp. 372-378, 2019. Available: http://www.jetir.org/papers/JETIR1502036.pdf.

[40] B. Ragavi, Determination of step angle for tracking the sun position of any location , 4th International Conference on Electrical Energy Systems (ICEES),2018.

[41] Quaid-e-Azam Solar Power, Quaid-e-Azam Solar Power (Pvt.) Limited, Pakistan (2020).

Chapter 5
Conclusions and Recommendations

Development of large scale solar power station is a vital step to counter energy crisis in Pakistan. This study is carried out to perform detailed analysis of solar energy harvested from installed solar system (Quid-e-Azam Solar Park Bahawalpur) having DC ratings 100 MW and comparing it with systems designed with different softwares keeping all important parameters same to ensure to reliability of designing. Keeping in view the outcomes of this study it can be concluded that output of solar panels is highly dependent upon various factors like air temperature, wind speed, daily average solar irradiance, humidity etc. Temperature above 25 $^{\circ}$C can affect the efficiency 10% to 16% of rated power output. Ambient temperature is always less than module temperature so wind is helpful to draw heat away from panel. Humidity also has inverse relation on performance of solar panels. All results and outcomes are discussed in this research. Generation comparison graph is shown below in figure 5.1

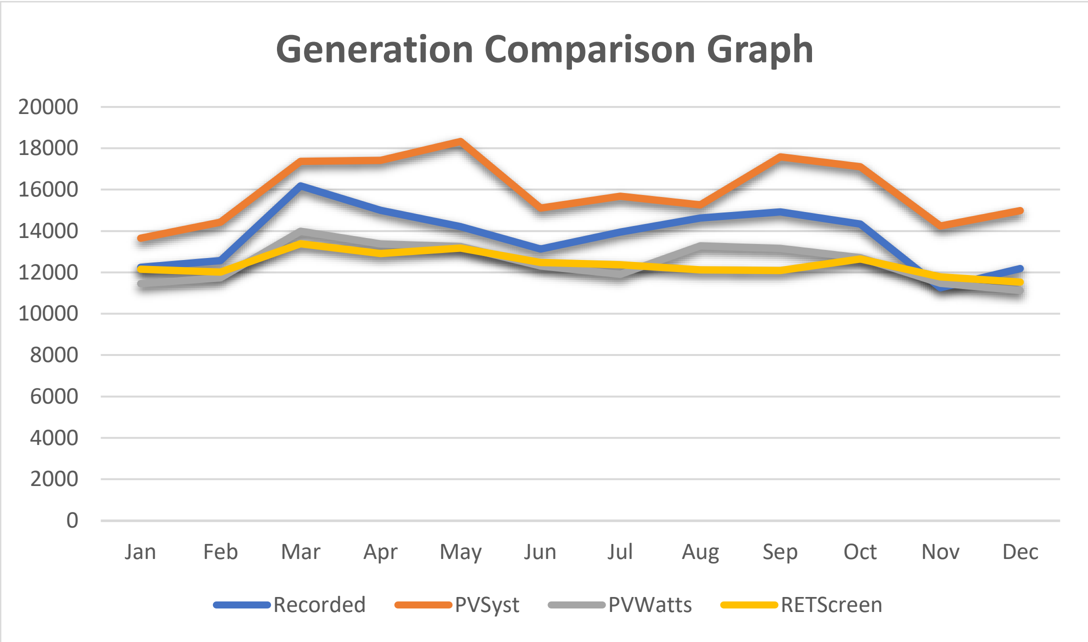


Figure 5. 1 Generation Comparison Graph

Following conclusion can be derived keeping in view recorded values and designed system.

- Temperature and humidity has inverse effect on efficiency of solar panels as temperature increases efficiency of solar panels decreases similarly output decrease with increase in humidity. Temperature recorded throughout the year is graphed with NASA provided temperature readings in figure 5.2 given below.

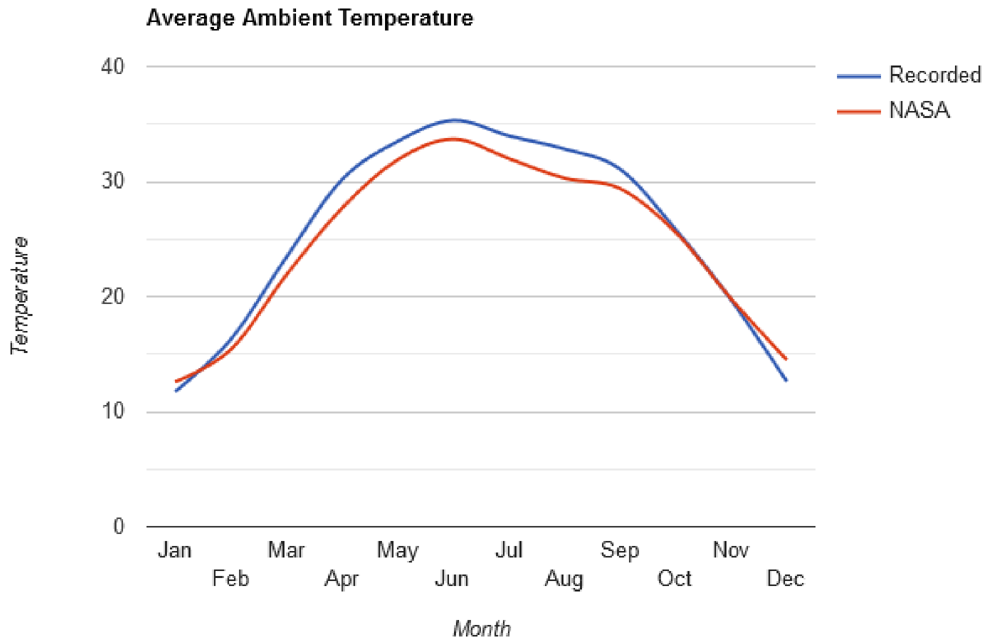


Figure 5. 2 Temperature Recorded Comparison graph

- Irradiance and wind speed have direct effect on output of solar panels with increase in irradiance. Average irradiance falling throughout the year for the targeted location is shown below in figure 5.3.

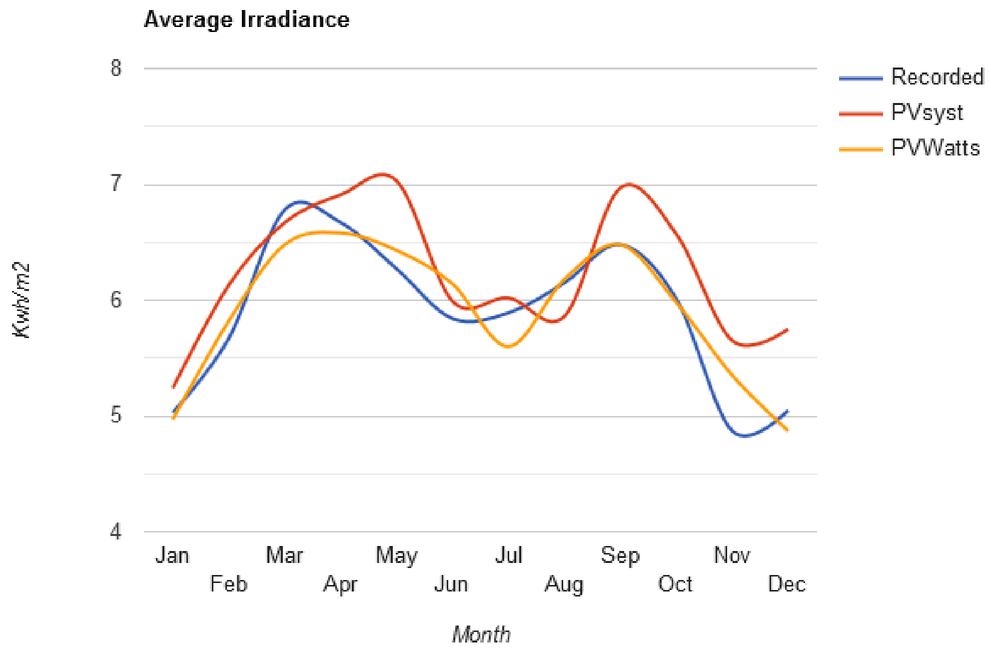


Figure 5. 3 Average irradiance Comparison Graph

- Output is increased similarly with more wind speed heat losses of panels are less and yield is more. Wind speed comparison graph is shown below in figure 5.4

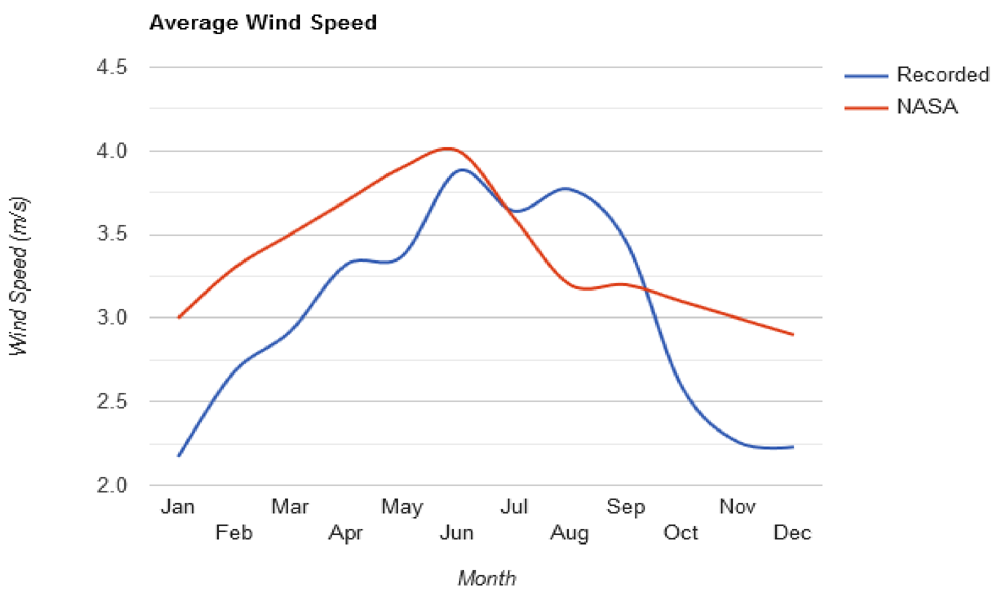


Figure 5. 4 Average wing speed comparison graph

- Comparing the output for whole year with RETScreen, PVsyst and PVWatts it might be concluded that PVWatts results are closer to recorded values of solar power plant. RETScreen output is also close to recorded generation. Comparison of generation predicted and recorded generation s given below in figure 5.5

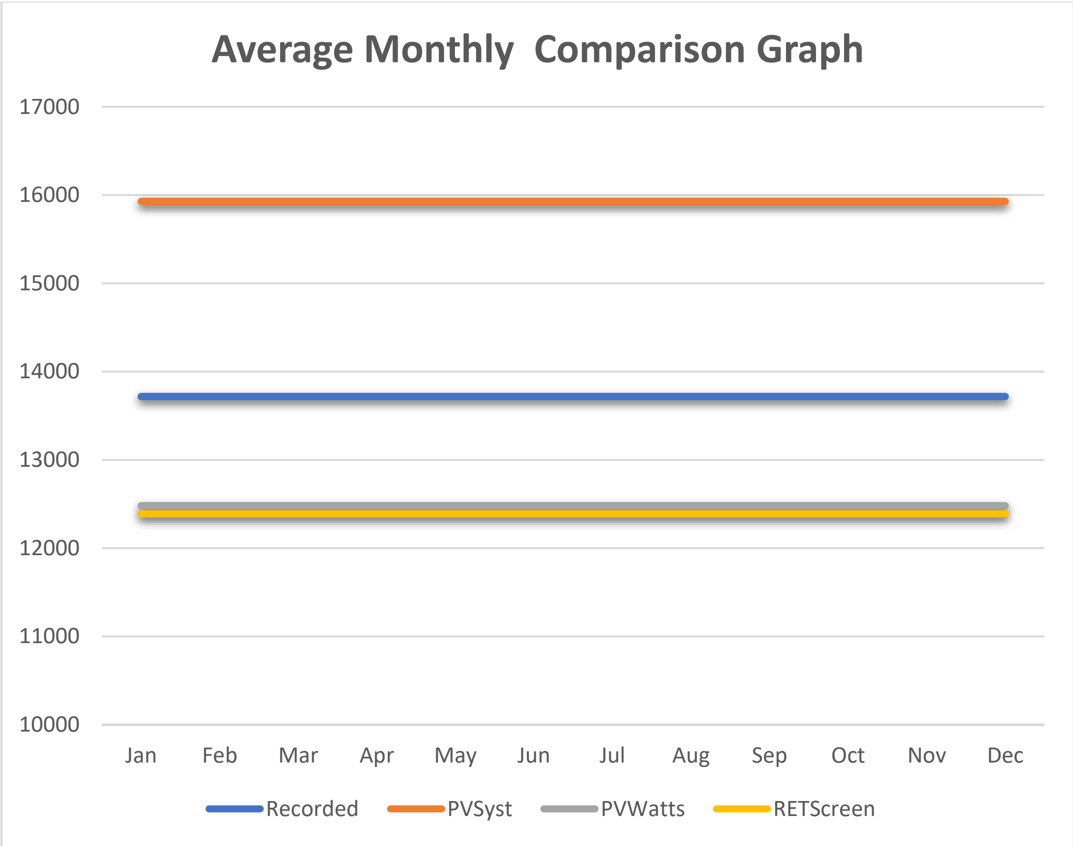


Figure 5. 5 Average Monthly Generation Comparison Graph

- If losses are reduced somehow output of plant can be increased.
- Semi or quarter yearly tracking will also yield more electricity for the same solar generation system.
- Highest generation is recorded in March and 2nd Highest in September despite having more sunshine hours in June and July, these statics elaborate how intense are the losses are, which are caused by high temperature on performance of solar system.

Statics shows that PVWatts and RETScreen are more reliable source of PV sizing as the generation output for the whole year predicted by these two softwares is quite close to output recorded by installed PV system at Quaid-e-Azam solar park. More over this study is also helpful to find out optimum angle for semi or quadrant yearly tracking by comparing output for each month at different tilt angles and if we somehow manage to control panel temperature in months of May, June, July and August we can have significant more generation with the same system.

Recommendations

This study does not only help to specify better tool for sizing but also provides information about generation trends of solar system throughout the year, despite more sunshine hours in summer generation is not maximum these statics give rise to another research problem that how much energy more we can yield with the same system in summer by somehow controlling panels temperature. In parallel to temperature effect one could also find out the percentage of more energy with the same system by maintaining the tracking angle semiannually or quarterly.