

**FEASIBILITY STUDY OF 1070 KW_p
PHOTOVOLTAIC POWER PLANT AT
LUBANIANWALI, SRI MUKTSAR SAHIB (PUNJAB),
INDIA.**

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of

MASTER OF ENGINEERING
in
Power Systems

Submitted by

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CERTIFICATE

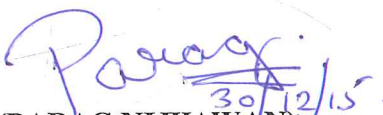
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ABSTRACT

This Thesis is centered on the feasibility study of photovoltaic (PV) power plant at Lubanianwali, Sri Muktsar Sahib (Punjab), India. For this, solar irradiance of this location has been used to evaluate the annual energy generated by the PV plant. The complete study has been carried out using PVsyst 6.39 simulation software. This study has been carried out with an aim to feed the electrical energy generation deficit of Punjab State power corporation Ltd. (PSPCL) in comparison to the total load demand of Punjab. At present, PSPCL is paying ₹ 7.04 per kWh to the private players supplying electrical power to PSPCL. In this work, it has been found that the actual cost to the company generating electrical power using PV is ₹ 6.63 per kWh after including the capital cost, loan interests, depreciation, running charges and maintenance costs. So, the proposed PV generation setup definitely will prove to be beneficial for profit making proposition for the company supplying electrical energy to PSPCL. In addition, reduction in carbon emissions with this proposed generation has also been evaluated which will definitely save the environment from global warming.

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INTRODUCTION

1.1 Motivation

Increasing population is leading to rise in energy demand. Energy has played a vital role in human social economical & political development. Industrialization and automation has increased our dependence on electric power. Man has mostly met his energy needs from conventional energy sources which are non-renewable like coal, wood, petroleum etc. These sources have been over exploited and are depleting fast at an alarming rate. Non-Renewable sources of energy pollute our environment and have a long lasting hazardous effect on overall ecology of earth. As a result humanity and our earth is facing severe climatic adversities. Over the last few years, international communities have accepted that our fossil fuel reserves, especially oil, are very limited and the problem of climate change caused due to consumption of fossil fuels needs urgent attention. The assessment reports by Intergovernmental Panel on Climate Change (IPCC) provides the knowledge on climate change. Renewable sources of energy like wind, solar, geothermal and tidal is playing and continue to play a vital role in addressing these problems.

India is a nation with fast growing economy. To fulfil India's development ambitions, energy is a key factor. To support nation's expanding economy meeting its electricity demand is a challenge. Soon, India may become the most populous country in the world. Today, India houses the world's 18 % population but only consumes 6 % of world's primary energy. In 2013, India's energy share in global energy demand was only 5.7%. According to a report by International energy outlook 2015, India has almost doubled its energy consumption since 2000. But, per capita energy consumption is still one- third of the global average. Also, 240 million people in India have no access to electricity. Coal accounts for 70% of generation of the Indian power sector. Realising the above scenario, India has to expand its base under Renewable Energy and energy efficient technologies.

Solar energy can empower it to attain ecologically sustainable growth, meet its challenge to meet its energy security and reduce its carbon emissions. India is a tropical country with ample sunlit days throughout the year. Solar energy can empower it to attain ecologically sustainable growth, meet its challenge to meet its energy security and reduce its carbon emissions. India is a tropical country with ample sunlit days throughout the year. Recent technological developments in the field of Solar Photovoltaic (PV) systems, a technology which converts the

direct sunlight of the Sun into DC electric power, has proved to be a breakthrough in adopting it for mass generation of power.

India's solar program JNNSM aims at encouraging public/private entities to capture solar energy potential. India has a potential to harness 748.98 GWp of solar power. Country has an installed solar power capacity of 3883.507 MW. Its state Punjab has a solar potential of 2.81GWp of which 195.27MW has been installed. Punjab lacks in conventional sources of energy. So, solar energy especially SPV systems could benefit largely for energy strapped state. Several state nodal agencies like PEDDA have been entrusted the duty to promote and develop the renewable energy projects.

1.2 Literature review

Allen M. Barnett [1] describes the photovoltaic (PV) effect based solar electricity. It redresses the questions like "Why don't we see these systems all over the world? Consumers in the United States are well-known for their attraction to new technology. Why aren't PV systems appearing on roof-tops in the U.S.?" The paper then answers the questions as "may be that grid-connected roof top systems are Too difficult to acquire, Too difficult to integrate with the grid, Too difficult to measure the energy and Too expensive". It concludes that it is necessary "to make PV systems user friendly, while reducing the component and system costs". The paper describes a "methodology to choose the right problems as an approach to PV development".

R. Ramkumar & J. E. Bigger [2] presents an overview of PV systems citing the activities in U.S. and around the world. It reviews different types of PV systems, their output characteristics and discusses different system configurations and provides their classification based on ratings. The paper further gives insight into PV system design, modelling and economics. It describes system types operating in the European nations, Japan and U.S., makes future assessment of technology, areas for research and development. The paper identifies issues which would require attention as the PV systems expand. It describes PV systems to be in evolving mode whose full potential hasn't been reached. It describes the factors for the growth of PV industry.

G. Ofualagba [3] explained the reasons which are arising the interests in PV technology. Paper gives description of PV systems – their components, areas of application and markets namely water pumping, off-grid and on grid purposes.

B. Marion *et al.* [4] studied performance parameters associated with Grid-Connected PV systems. Paper states that reference yield (Y_r), final PV system yield (Y_f), PVUSA ratings and performance ratio (PR) are four performance parameters which can be used to analyse the performance of grid-connected PV systems. Paper further defines these parameters and discusses their appropriateness for performance evaluation and providing required information for PV system design by demonstrating them for different geographic locations, designs and technologies. It also discusses “methodologies for determining system AC power ratings in the design phase using multipliers developed from measured performance parameters”.

V. Lughì *et al.* [5] describes the growing installed capacity of PV systems and shows concern over high production cost of energy. The paper discusses some important research progress on new PV devices and materials like use of cadmium telluride thin films and nanostructured PV materials which may lower the generation cost. The paper points out to the problem of different characteristics of large size PV plant in comparison to smaller ones and analyses it for the provision of guidelines and recommendations for proper design of large PV plants. The paper stresses for the proper choice of power conditioning systems and simulation tools for design purpose.

Kosuke Kurokaw *et al.* [6] studied the case assuming the installation of a 100 MW PV generation system on world deserts like Gobi, Thar, Sahara, Sonora, Great Sandy and Negev desert due to large levels of irradiation & land area. The paper studied the above case detailing the design and performed Life-Cycle Cost (LCC) based the cost analysis. The generation cost was found to be economical.

M. C. Cavalcanti *et al.* [7] studies the comparative efficiency for topologies in PV energy systems. A study of losses is presented to compare compare different topologies to choose best efficiency option. “The systems are also tested with photovoltaic generation as well as current harmonic and reactive power compensation simultaneously.” The paper proposes a design to test different loads and efficiency for different PWM techniques. It concludes that the proposed design shows good performance.

B. Bekker [8] simulated irradiation of locations in South Africa in SunSim software package and evaluated their PV performance. King’s performance model is used to estimate the PV

array energy output at tilted surfaces. The paper analyses the influence of temperature and irradiation data on tilted surfaces PV energy generation intended to find the optimal tilt angle and best solar tracking arrangements for fixed PV panel. Further, the paper investigates the generation cost of PV energy.

Saeb M. Besarati *et al.* [9] developed solar maps in paper to give inputs into the levels of solar radiation which acts as a database for future investments in Iran for solar energy. Further, 5 MW PV power plant outputs was investigated in 50 cities of Iran and concluded that cities in southern and central part of Iran had more potential than the ones near Caspian Sea.

A. Khelif *et al.* [10], Feasibility of the plant study should take into account several issues like investment cost, total annual cost of the project. In the case of the AFRA power plant [4paper], profitability of the project is very sensible to fossil fuel cost, with a PV generator of 35 kWp and a battery capacity of 1100 Ah. The break-even point will reach 0.34€/l, if the recuperation of diesel generators is not considered. Beyond this fuel cost the project will be profitable.

M. EL-Shimy [11] studied project feasibility of 10 MW PV-grid connected power plant using RETScreen version 4.0 software at 29 sites in Egypt to analyse the energy production, financial viability and greenhouse gas (GHG) emissions with maximum capacity factor of 33.7% at Waahat Kharga and minimum capacity factor of 27.6% at Safga.

Constantinos S. Psomopoulos *et al.* [12] conducted studies on three software packages PVGIS, PVWatts and RETScreen to compare their primary differences in the results and usage and finds them to be user-friendly even for untrained users. PVWatts is confined to calculations of PV systems within the US borders only. PVGIS is confined to assessment of Europe and Africa and it seems to evaluate the produced energy with more accuracy than PVWatts and RETScreen. PVGIS utilizes more accurate databases for any specified location. Due to NASA's meteorological stations on each country, RETScreen has a larger location database. RETScreen is a tool which could be not only used for PV systems but also for other renewables as well.

Ashish Verma and Shivya Singhal [13] studied the various loss parameters in the PV energy installations and other factors for solar PV performance like performance ratio (PR), cumulative utilization factor (CUF) and their optimization. It discusses various loss factors like

irradiance, soiling, mismatch effects, Maximum Power Point Tracking (MPPT) losses etc. and gives recommendations for optimizing the plant performance.

1.3 Objective

The objective of this thesis is to study the feasibility of 1070 KWp PV power plant at village Lubanianwali, Sri Muktsar Sahib District of Punjab which is at proximity of grid. Optimization of the power plant is done with respect to the energy production and performance ratio of the system. After finalizing the different system components, simulation of the energy yield, cost of generation of electricity and reduction in carbon emissions has been performed. Also, the simulation is performed over fixed tilt plane modules and seasonal tilt adjustment of the modules. An investigation is performed concerning the change in of the energy yield, cost of generation of electricity and reduction in carbon emissions, if the seasonal tilt adjustment is placed.

A PV system is a complicated system constituting multiple variables and disciplines that have to work together for achievement of a good PV system. This thesis not only considers the electrical behavior of a PV system but also its economic and environmental aspects. The simulation program used in this thesis is PVsyst 6.39. PVsyst is a comprehensive PV simulation software.

1.4 Organization of the Dissertation

Chapter 1 presents the Introduction of proposed work, motivation, literature review, and objective of the work.

Chapter 2 gives a basic outline to a grid-connected PV system. This chapter includes elementary introduction to the electrical characteristics of the PV cell and the inverter.

Chapter 3 presents an organized and detailed theory & order of the steps that are essential to perform a simulation in PVsyst software of a grid-connected PV system:

1. Project
2. Orientation
3. System
4. Detailed losses
5. Horizon
6. Near shadings

This chapter defines some parameters required to perform the simulation and provides some background information.

Chapter 4 details the economic evaluation of the project. It presents different conditions and costs associated with the project and the tariff for power sale.

Chapter 5 constitutes the simulations performed, simulation settings in PVsyst and results, both in tabular and graphical format.

Chapter 6 presents an account of carbon balance and explains the amount of carbon dioxide emissions could be reduced by the solar power plant in its lifespan.

Chapter 7 includes the conclusion and the future scope of the work.

PHOTOVOLTAIC (PV) SYSTEMS

2.1 PV systems Description

PV systems can be mainly classified into two different systems:

- Stand-alone PV systems
- Grid- connected PV systems

A stand-alone PV system includes

- Solar modules – provide direct current (DC) power to the battery.
- Charge controller – manages the charge of the batteries to ensure a long optimal lifespan.
- Battery bank – stores electrical energy.
- Inverter – converts the DC power stored in the batteries to alternating current (AC).

Stand-alone systems (Fig. 2.1.1) find their application mainly in areas which are not connected to the grid like distant rural areas, tough mountainous terrain, street lighting, parking lots etc.

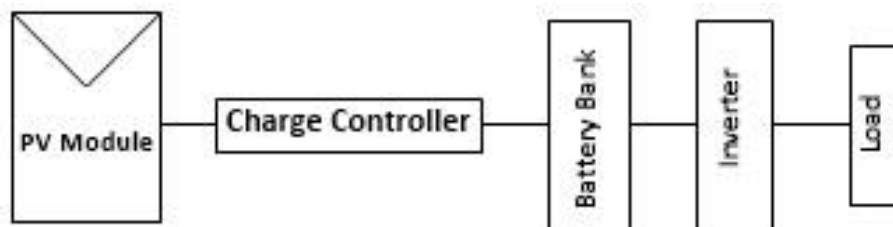


Fig. 2.1.1: Schematic diagram of a stand-alone PV system

Grid-connected PV system constitutes mainly modules, mounting systems, cables, junction boxes, inverters, protection and disconnection switches, lightning protection system and meters. A basic structure is shown in figure below.

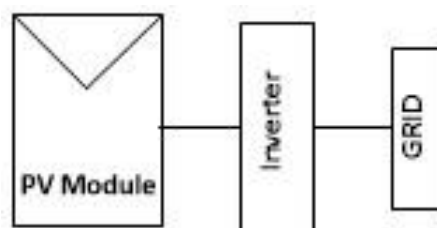


Fig. 2.1.2: Schematic diagram of a grid-connected PV system

2.2 PV Cell, PV Module, PV String and a PV Array

PV cell: PV cells are similar to diodes. A PV cell is a specialised semiconductor diode which converts the light into Direct Current (DC). It is made of two semiconductor layers (least), one of the layers is p-type and the other one is n-type. When sunlight particles called photons strike the surface of the cell, few of them get reflected, few get absorbed while others get pass right through. When by the n-type layer of the photovoltaic cell absorbs enough photons, electrons from the n-type layer semiconductor material are freed. These freed electrons naturally travel to the p-type layer forming a voltage differential. When an external load is connected across these two layers, electrons flow through the circuit leading to creation of electricity. A cell can produce very small amount of energy at very low voltage.

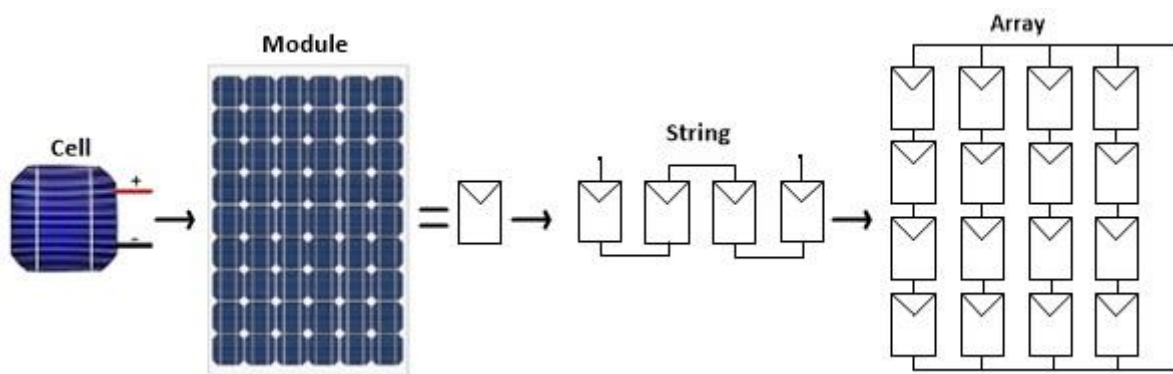


Fig. 2.2.1: PV cell, PV module, PV string, PV array

PV module: multiple PV cells connected in series, form a module (also called panel). If a module has 54 cells and each cell has a peak voltage of 0.5 V, the module rated peak voltage will be 27V.

PV string: Solar modules wired in series form a PV String. Taking the above example of a 54 cell module, if each module has I_{sc} of 7A, 4 modules form a string, then the string peak voltage will be $4 \times 27V=108V$ and string I_{sc} of 7A.

PV Array: PV strings wired in parallel form a PV array. As per above example, if 4 strings are wired in parallel to form an array of 16 modules, its peak voltage will be 108V and I_{sc} will be $4 \times 7A= 28A$.

2.3 Electrical Characteristics of a PV Cell, PV Module, PV String and a PV Array

Electrical properties of a PV cell can be largely described as a large diode (see Fig. 2.3.1).

When the diode is subjected to electric potential the current flows through it as shown in the

figure. The characteristic curve follows the first quadrant. The current I_F starts to flow in forward direction at a particular voltage called threshold voltage (V_T). The current doesn't flow in the reverse direction until the voltage exceeds the breakdown voltage (V_B). The breakdown voltage can destroy the diode.

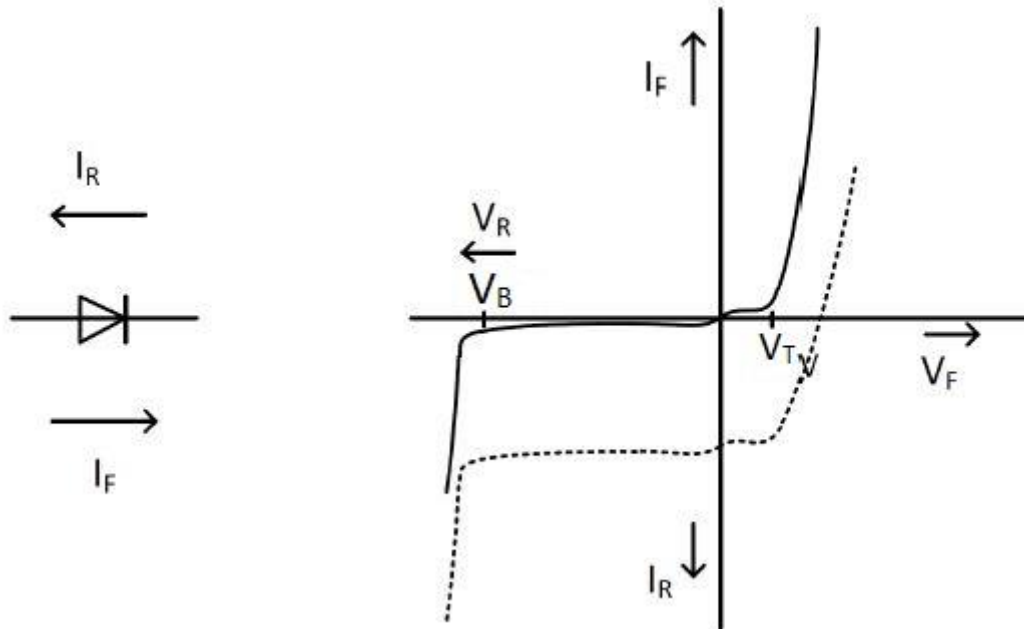


Fig. 2.3.1: V-I characteristics of a diode. F - Forward, R – reversed

Solar cell can be explained using single diode model with a diode in parallel with a current source (PV cell). As the cell is illuminated, it will produce a photoelectric current (I_{pv}). The magnitude of the photoelectric current shifts the diode characteristic curve downwards in the third and fourth quadrant, seen as the dotted line in Fig. 2.2.2 [14]

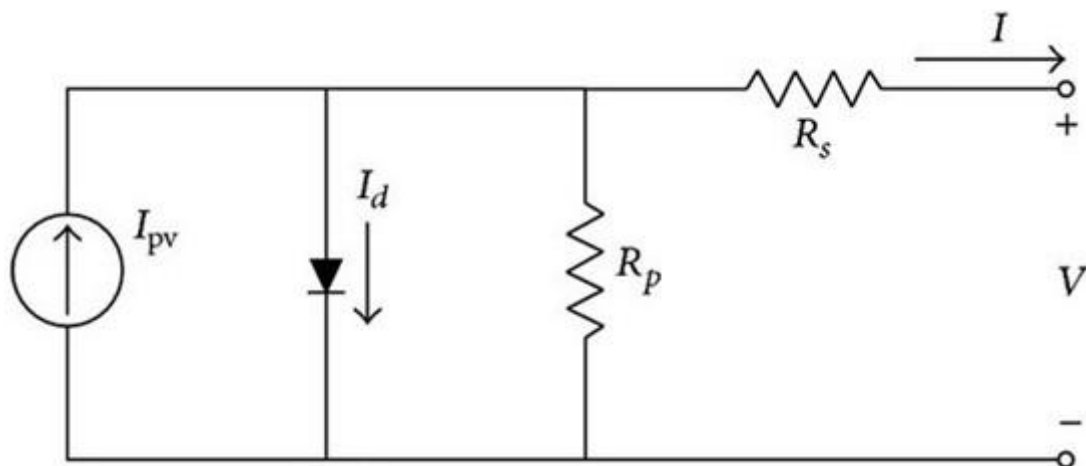


Fig. 2.3.2: Single diode model for V-I characteristics of PV cell

The single-diode model [15] is the standard model used to represent a PV cell (illustrated in Fig. 2.3.2). The voltage drop is represented by drop across a parallel resistance (R_p), which occurs when the charge carriers drift from the semiconductor to the electrical contacts. In order to represent leakage currents, a series resistance (R_s) is added.

The V-I and power characteristics of an array are shown in Fig. 2.3.3. The Maximum Power Point (MPP) in this figure demonstrates the maximize production operating point of the cell, with respect to current and voltage.

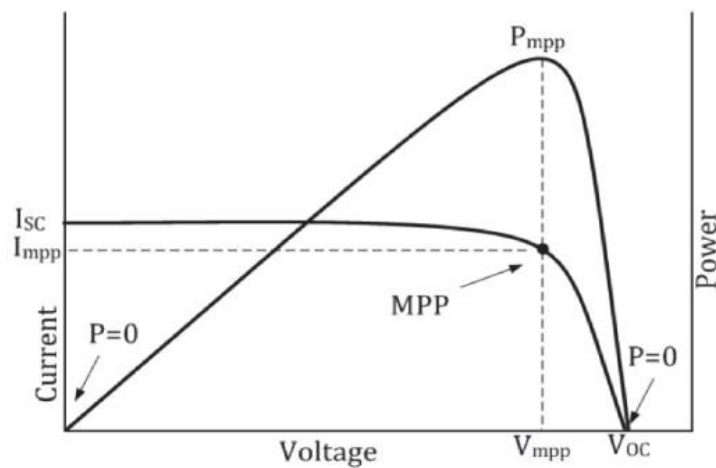


Fig. 2.3.3: V-I and power characteristics illustrating Maximum power point.

Series connection of modules increases the voltage along the abscissa axis. Parallel connection of modules increases the current on co-ordinate axis as seen in the Fig.2.3.4.

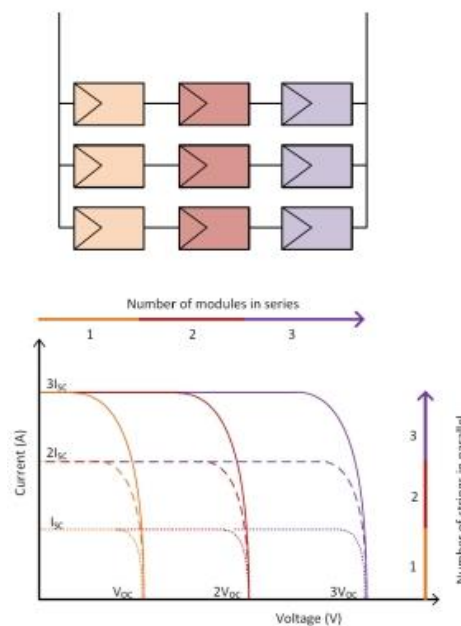


Fig. 2.3.4: V-I characteristics of a PV array

2.4 The Inverter

The inverter converts DC current from the PV installation to AC current. The transformed power is then sent to station transformer which steps the voltage in parity with the grid. It matches the voltage and phase of the electricity grid. For AC current conversion, semiconductor switches produce pulses of voltage, using pulse width modulation to achieve a precise approximation of a sine wave output. The inverter not only performs the function of a DC-AC switching but also has a maximising function to maximise the usefulness and functionality of the solar modules. It also has maximum power point tracking (MPPT) control and voltage regulation function.

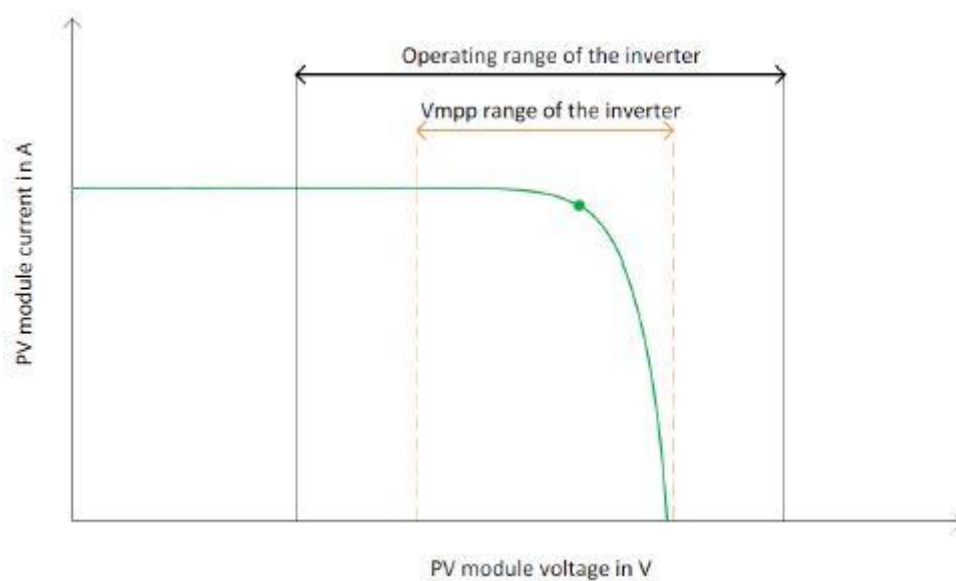


Fig. 2.4.1: V-I characteristics showing MPP and operating range of a solar inverter

MPP and operating range of an solar inverter are shown in Fig. 2.4.1 on PV module V-I characteristics graph. Within the MPP range, the inverter has a tracker, called Maximum Power Point Tracker (MPPT). The output of the solar modules changes according to the solar cell modules temperature and solar radiation intensity. To apt to these changes and make the solar modules function in maximum power mode, MPPT Control serves the purpose. The MPPT locates the MPP, marked with a circle in the figure, in order to obtain maximum power possible from the system. For the inverter to function, the PV array voltage should match the operating range of the inverter. Inverters provide electric isolation between the DC input side and the AC output side. In absence of this isolation between the DC and AC side of the system, DC currents might be injected into the grid leading to harmonic distortion. [16]

PVsyst

Simulation is the most widely used and accepted tool in operation research, system modelling and analysis. Simulation tools have a wide range of applications in different fields like communication systems, health care, military, transportation systems etc. Simulation tools are software packages which can almost simulate real world like situations to assess the viability and validity of, different conditions or cases or analyse the performance of systems. In context with the Solar PV systems, numerous simulation softwares are available to evaluate the performance and other parameters associated with the Solar PV systems. These include HOMER, RETScreen, NREL Solar Advisor Model, PVsyst 6.39, PV F-Chart, SolarPro, SolarDesignTool, INSEL, TRNSYS, PV*SOL Expert etc.

PVsyst is one of the most comprehensive softwares in the field of PV systems. Andre Mermoud developed PVsyst at the University of Geneva. [17] PVSYST is a software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transport) PV systems, and includes extensive meteo and PV systems components databases, as well as general solar energy tools. [18] PVsyst offers the choice for simulating a preliminary design or a project design. Shading calculations in PVsyst has a higher accuracy than other tools. This study was carried out using the PVsyst software 6.39 version, to calculate the energy production, cost of energy and carbon emissions reduced by the PV installation.

3.1 Project: Geographical Location and Meteorology

The optimal tilt of the PV modules is influenced by the geographical location of the project and the local weather conditions and is, therefore, of great importance. The site in this study is a village called Lubanianwali in Sri Muktsar Sahib District of Punjab state in India. The location of the proposed site is at few meters away from a 66 kV substation of PSPCL for power evacuation.

Table 3.1.1: Geographical co-ordinates of Lubanianwali

Latitude	30.59 ⁰ N
Longitude	74.55 ⁰ E
Altitude	197m above sea level
Time Zone	+5.5hrs

3.1.1 Solar Radiation and Meteorology

The energy generated by a PV module depends on amount of radiation it receives at its specific location. The Sun's energy is emitted primarily as radiation. When the Sun's radiation enters the atmosphere, a part of it gets scattered or absorbed due to its collision with clouds and air molecules (illustrated in Fig. 3.1.1). The scattered radiation can either get re-emitted into the atmosphere or reach the module's surface, this is called diffuse radiation. The radiation which is not reflected or absorbed (direct radiation or beam radiation) reaches the earth's surface in a direct line from the Sun. Some of the radiation gets reflected by the ground and reaches the module surface. It is known as Albedo radiation. Beam, diffuse and albedo radiation constitute the Global radiation.

Due to absorption and scattering, solar radiation reaching the Earth's surface decreases and is extremely variable. The spectral composition of the radiation at the earth's surface is different from the radiation above the atmosphere i.e. Extraterrestrial radiation.

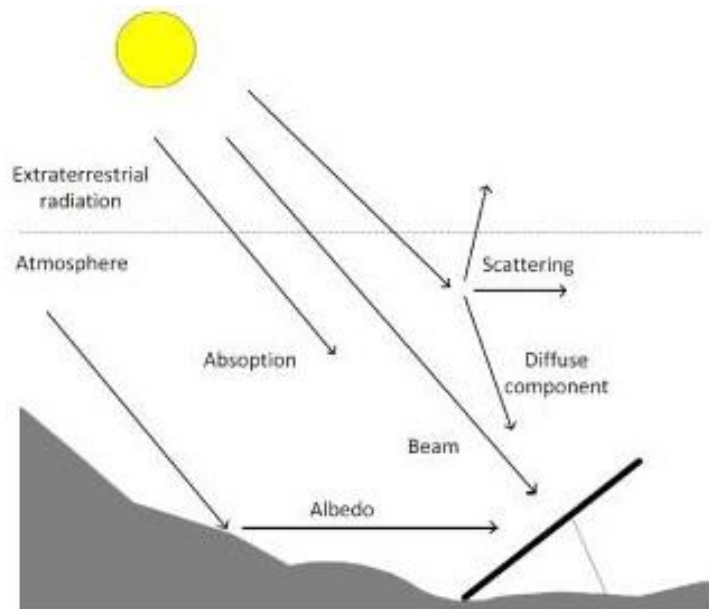


Fig. 3.1.1: Path of Solar radiation in the atmosphere

Air Mass (AM) is the concept which characterises the effect of a clear atmosphere on sunlight,

equal to the relative length of the direct beam path through the atmosphere.[19] The radiation from the sun on a clear summer day at sea level, at zenith, corresponds to Air Mass 1 (AM = 1); else the Air Mass is approximately given by

$$AM = \frac{1}{\cos \theta_z} \quad (3.1.1)$$

where θ_z is the zenith angle between the sun and the line to a point directly overhead (see Fig. 3.1.2)

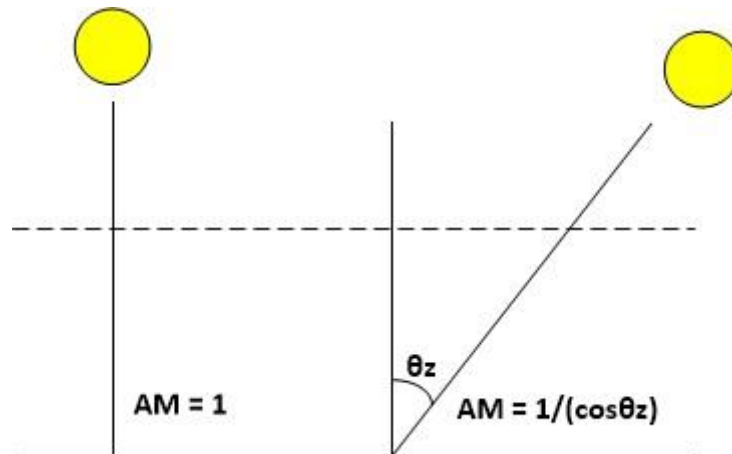


Fig. 3.1.2: Air Mass

The PV modules are rated at STC (Standard Test Conditions), which are:

- AM = 1.5
- Solar radiation = 1000 W/m²
- Cell temperature = 25° C

But in actual field conditions the operating module temperature is higher than the rated STC. So it is important to determine the expected operating temperature of the PV module in order to determine the power output of the solar cell. The Nominal Operating Cell Temperature (NOCT) is the temperature attained by open circuited cells in a module under the following conditions:

- Ambient temperature = 20° C
- Solar radiation = 800 W/m²
- Wind speed = > 1 m/s
- AM = 1.5
- Mounting = open back side

On a clear day, the typical value of AM on the Earth’s surface is 1.5. Although global irradiance can peak up to 1000 W/m² or even above. Highest irradiance levels are found near the equatorial region but average irradiance levels are below these values due to clouds presence in this region. Highest Mean irradiance levels are found in the tropical region. i.e. Tropic of Cancer and Tropic of Capricorn. Fig. 3.1.3 shows India’s Global Horizontal Irradiance (annual average). [20] It clearly shows that the irradiance levels increase with decrease in latitude.

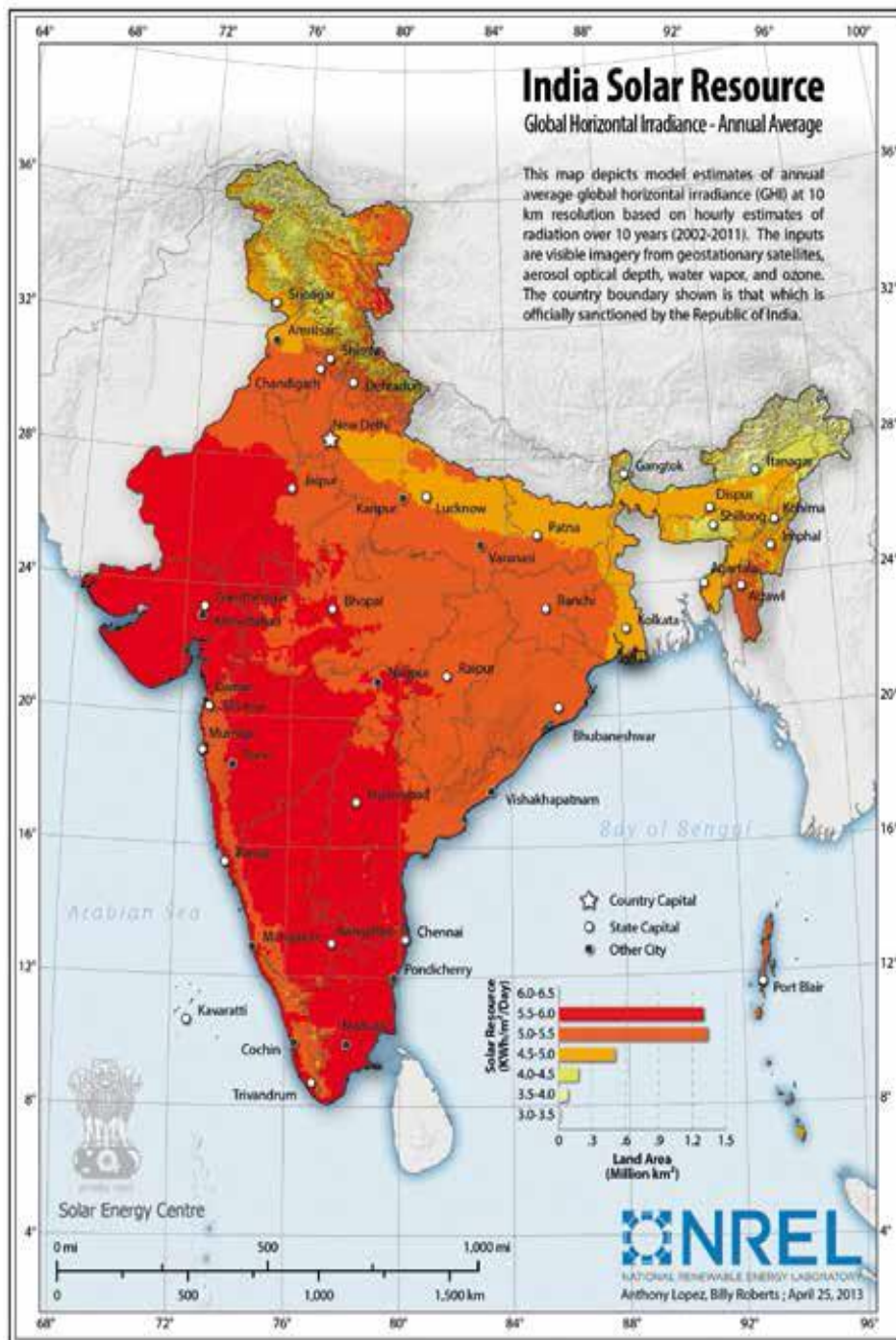


Fig. 3.1.3: Solar irradiation map of India showing Global Horizontal Irradiance (annual average).

Position of the Sun

The Sun's location is defined by two angles:

- Altitude (α)
- Azimuth (ψ)

The angle between the sun and the ground is the altitude angle of the sun. This angle is always lies between 0° and 90° . The angle between north and the point where the sun is positioned is called the Azimuth angle. Altitude and azimuth can be determined from [21] the following equations:

$$\sin \alpha = \sin \delta \cdot \sin \phi + \cos \delta \cdot \cos \phi \cdot \cos \omega \quad (3.1.2)$$

$$\cos \psi = \frac{\sin \alpha \cdot \sin \phi - \sin \delta}{\cos \alpha \cdot \cos \phi} \quad (3.1.3)$$

Where δ is the declination, ϕ is the latitude and ω is the hour angle. The deviation of the sun from above the equator is called angle of declination. The difference between the noon and the desired time of the day expressed in terms of degrees is called the solar hour angle.

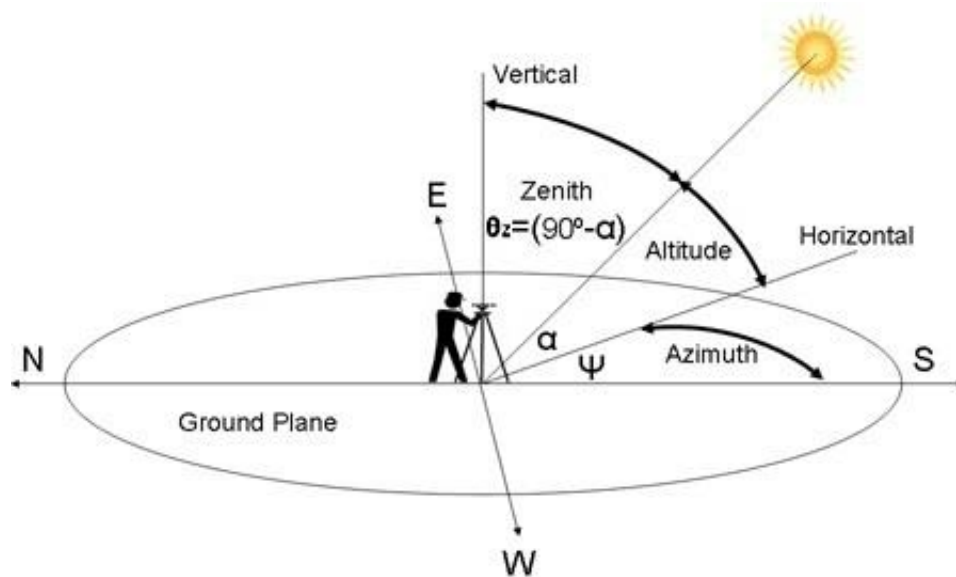


Fig. 3.1.4: Azimuth and Altitude for Northern Latitudes[22]

The meteorological data provided on NASA-SSE website provides information related to the Azimuth and Altitude of Sun at any particular longitude and latitude. It provide complete info on monthly mean hourly azimuth and altitude angles of Sun at a given location using geographical coordinates.

Effect of Irradiance and temperature on PV cell

Ideally, PV systems should operate at nominal conditions called STC conditions but it rarely happens due to regular change in weather i.e. varying levels of Irradiance and temperature with time. So, the performance of PV cells/ modules is highly dependent on irradiance and temperature.

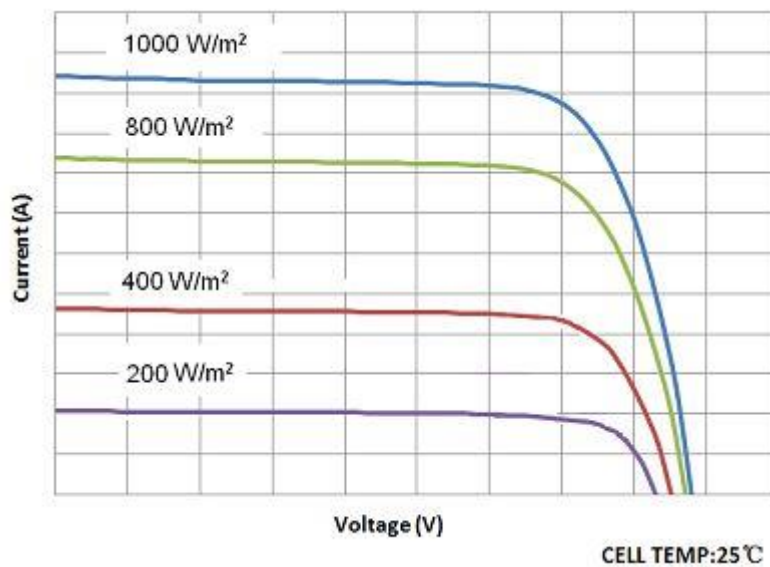


Fig. 3.1.5: Cell/Module V-I curve showing varying irradiance and constant temperature. [23]

The Fig. 3.1.5 shows that increasing the irradiance levels on the PV cell/ module surface highly increases the short circuit current whereas the open circuit voltage remains constant, keeping the cell temperature constant.

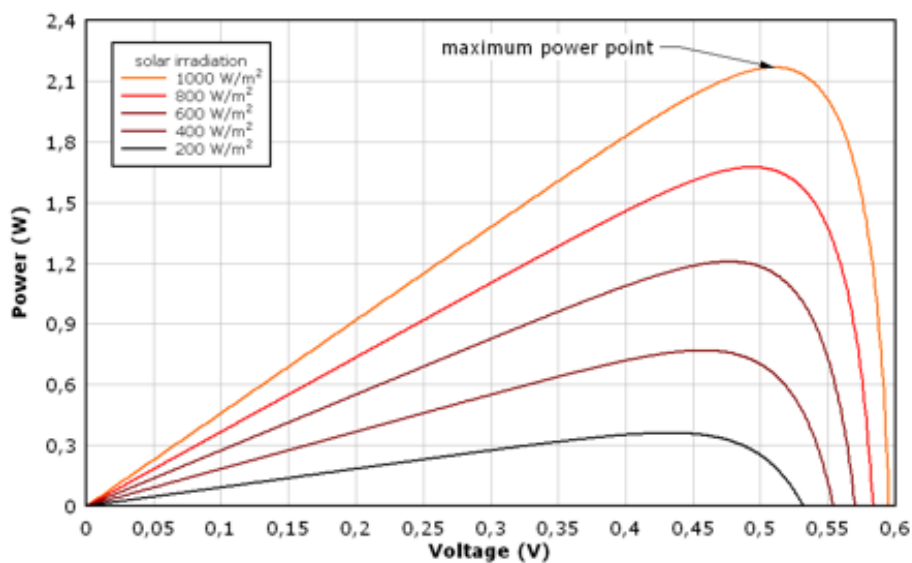


Fig. 3.1.6: Cell/Module V-P curve showing varying irradiance and constant temperature. [24]

The power output of PV cells/modules is roughly directly proportional to irradiance. Fig. 3.1.6 shows the V-P curve with varying irradiance and constant temperature. The power curve will scale proportionally as the irradiance striking the cell decreases,. The MPP of the solar cell also changes.

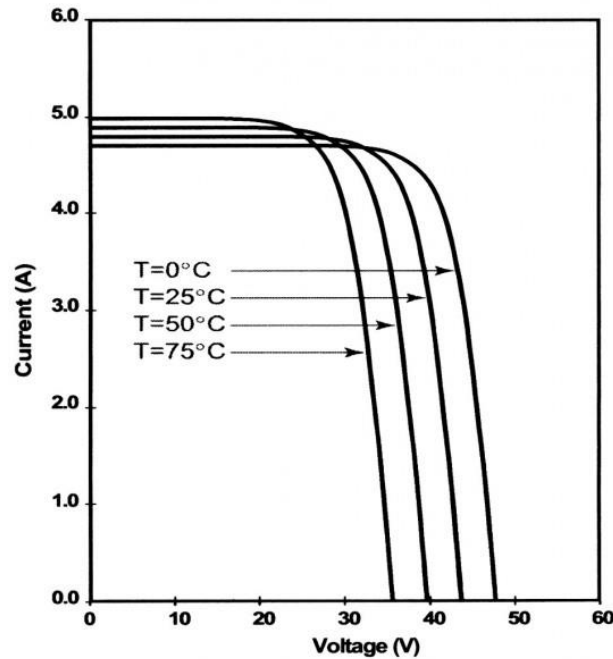


Fig. 3.1.7: V-I curve showing effect of temperature at constant irradiance level. [25]

From Fig. 3.1.7. It can be realised that the change in temperature affects the open circuit voltage greatly whereas the short circuit current increase slightly.

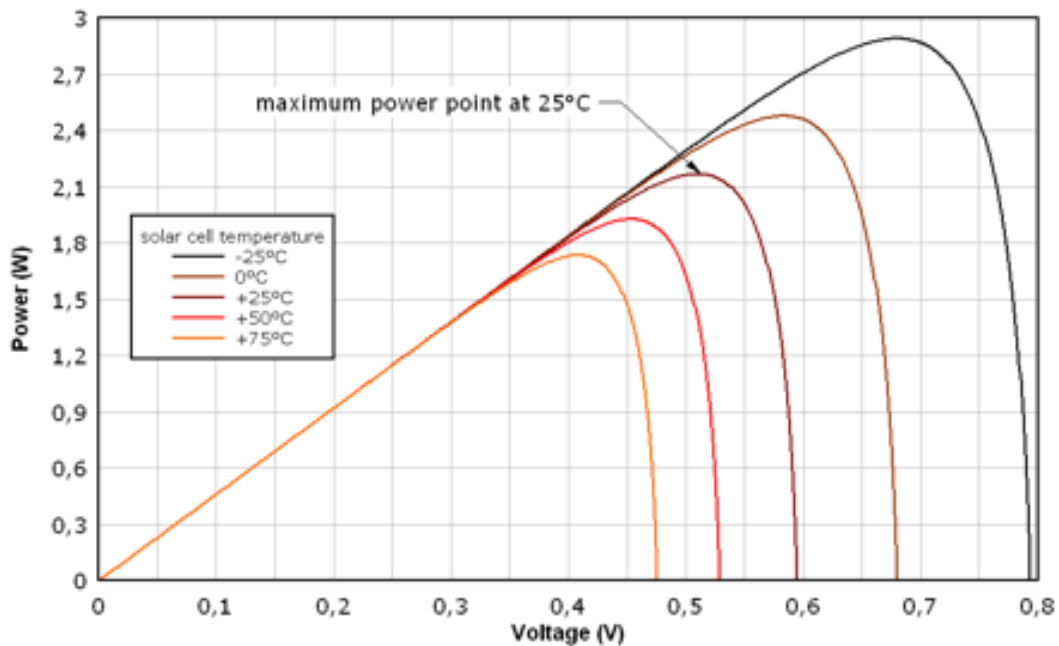


Fig.3.1.8: P-V curve showing the effect of temperature at constant irradiance level. [26]

Fig. 3.1.8 demonstrates the effect of temperature on the power curve. Power curve scales proportionally with the rise in temperature. Under constant irradiance, Power output decreases with rising cell temperature.

3.1.2 PVsyst's Geographical and Meteorological Considerations

The project location is the first step in project design using PVsyst. The site location is added to the database either by directly entering the latitude and longitude coordinates or using the interactive map option. Using the interactive map, one can directly pin the site on the map and PVsyst retrieves its geographical coordinates, altitude and time zone.

The monthly meteorological data can be imported from Meteonorm 7.1 or NASA-SSE. Meteonorm 7.1 is considered conservative as it often gives values lower than average which results in lower energy yield in simulations far from the actual real time yield. The monthly meteo tab displays monthly meteorological data which include horizontal global irradiation, horizontal diffuse irradiation and ambient temperature. The monthly mean values for wind velocity could be provided additionally. Meteo files from other sources like Satelight (for Europe), US TMY2 (for USA), WRDC, Helioclim (for Europe), PVGIS-ESRA (for Europe and Africa) also can be imported to PVsyst.

Meteorological data for the project site (see Table 3.1.2) has been imported from NASA-SSE.

Table 3.1.2 Meteorological data of the project site

Month	Hor. Global kwh/m².mt h	Hor. diffuse kwh/m².mth	Extra- terrestrial kwh/m².mth	Clearness index	T Amb °C
January	106.3	29.8	181.4	0.586	11.1
February	122.6	32.2	202.0	0.607	14.2
March	164.9	46.8	271.2	0.608	20.6
April	184.5	56.4	306.5	0.602	27.1
May	200.9	67.6	344.5	0.583	31.3
June	195.6	69.6	343.2	0.570	33.0
July	180.7	74.1	349.7	0.517	30.8
August	171.7	67.0	328.1	0.523	29.3
September	159.3	51.6	279.8	0.569	27.9
October	147.6	38.1	240.2	0.614	23.9
November	118.2	27.0	186.7	0.633	18.5
December	101.1	26.3	168.8	0.599	13.1
Year	1853.5	586.5	3202.2	0.579	23.4

Sun path

Next step involves the construction of the sun path for the location, as shown in Fig. 3.1.9

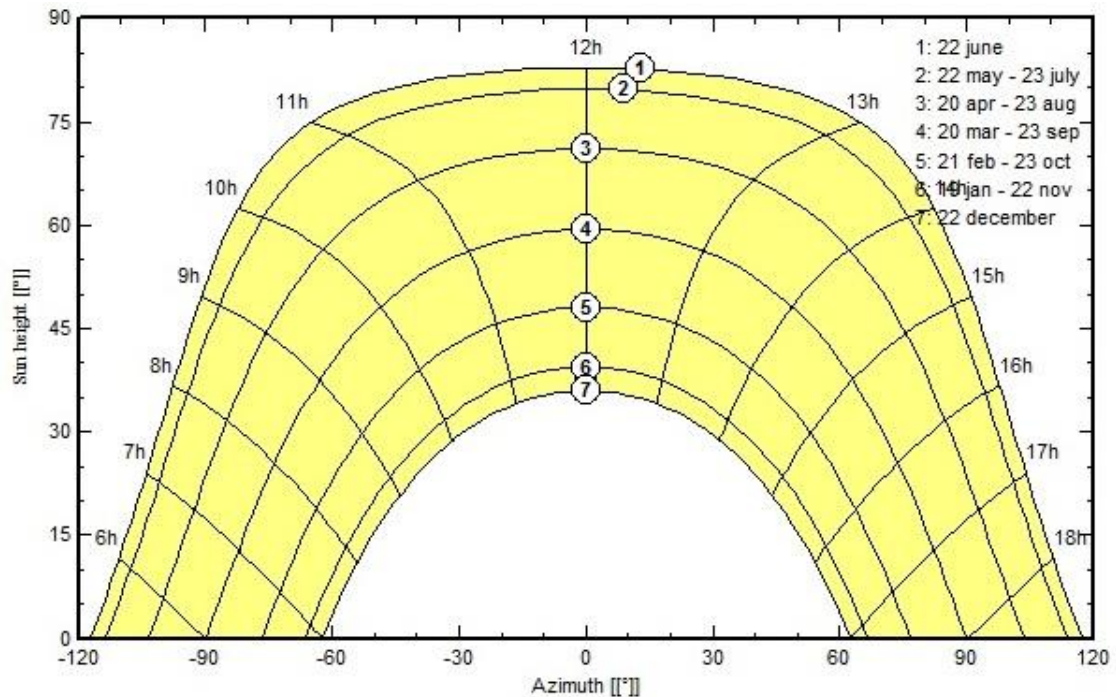


Fig.3.1.9. Solar paths at Lubanianwali, Sri Muktsar Sahib, India (Lat 30.6°N, Long 74.6°E, alt 197m)

Albedo Factor & other parameters

Further, monthly albedo values can be defined or a common value can be set. The default value of albedo is 0.2. The albedo coefficient is the fraction of global incident irradiation reflected by the ground in front of a tilted plane. [26] Albedo values signifying the surroundings within the PVsyst are listed in Table 3.1.3

Table 3.1.3: Albedo values given in PVsyst [26]

Surroundings	Usual albedo values
Urban situation	0.14 - 0.22
Grass	0.15 - 0.25
Fresh grass	0.26
Fresh snow	0.82
Wet snow	0.55 - 0.75
Dry asphalt	0.09 - 0.15
Wet asphalt	0.18
Concrete	0.25 - 0.35

Red tiles	0.33
Aluminium	0.85
New galvanised steel	0.35
Very dirty galvanised steel	0.08

The albedo value for the project site is set to default 0.2 value. Next step is to set the Site-dependent design parameters which includes reference temperatures for array design by respect to inverter input voltages. The default values of these parameters is listed in Table 3.1.3

Table 3.1.4: Site-dependent design parameters (default)

Parameter	Value
Lower temperature for VmaxAbs limit	-10°C
Winter operating temperature for VmppMax design	20°C
Usual operating temperature under 1000 W/m ²	50°C
Summer operating temperature for VmppMax design	60°C

Site-dependent design parameters for the project site simulations are set to default. Other design parameters include array max. Voltage is set to IEC (usually 1000 V) and μV_{oc} is selected from one diode model. The limit overload loss for design is set to default 3.0 %. The limits with shadings is set to default.

3.2 Orientation

Fixed tilted PV modules are used for this project. Options available under field type are:

- Fixed Orientation Planes.
 - Fixed Tilted Plane
 - Several Orientations
 - Seasonal Tilt Adjustment
 - Unlimited Sheds
 - Unlimited Sun-shields
- One-axis tracking planes
 - Tracking tilted or Horizontal N-S
 - Tracking, Horizontal axis E-W

- Tracking, vertical axis
- Tracking Sun-shields
- Two-axis tracking planes
 - Tracking Two-axis
 - Tracking Two-axis, frame NS
 - Tracking Two-axis, frame EW

Tracking systems if included in the system can increase energy yield by 25% but come with an additional cost and due to mechanical parts involved, require more maintenance. In order to, Obtain maximum possible irradiation, the modules should be directed towards geographic south. This is achieved at an azimuth angle of 0° .

3.2.1 Optimum Tilt Angle

Solar modules should be able to collect maximum possible radiation. Tilt angle of the modules should be optimum to maximise the performance of the installed PV System. Earth's revolution around the sun, causes seasons, leading to change in irradiance levels at any place on earth. This difference can be compensated by optimising the tilt angle β . The optimal tilt angle β_{opt} is defines as the angle of tilt for solar modules at which it receives highest annual global irradiation. β_{opt} depends on both latitude and local climate. The rule of thumb with regards to the highest annual performance is a tilted angle approximately equal to the latitude of the site. i.e. $\beta_{opt} \approx \phi$.[27]

Orientation panel in PVsyst shows the corresponding Transposition Factor (TF) which is defined as the ratio of the incident irradiation (GlobInc) on the plane, to the horizontal irradiation (GlobHor). i.e. what you gain (or loose) when tilting the collector plane.[28] The optimal tilt angle is found at zero TF. TF helps in optimizing the tilt angle. Graph of the Transposition Factor as a function of the plane tilt and azimuth is shown in Fig. 3.2.1. These graphs also point to the actual choice by a violet dot on the curves. The optimisation is with respect to annual irradiance yield.

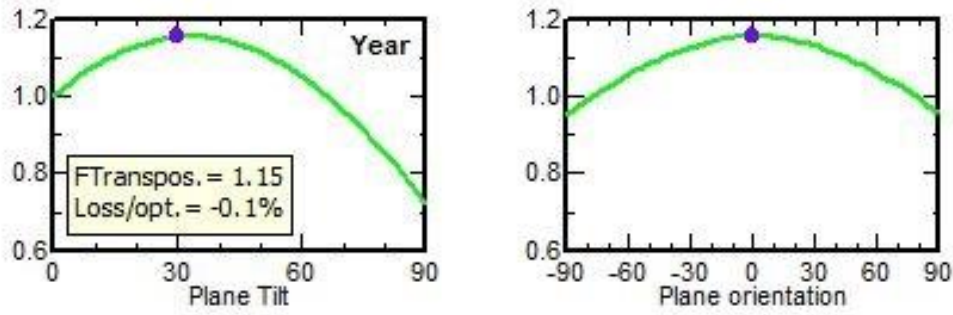


Fig. 3.2.1: Graph of the Transposition Factor as a function of the plane tilt and azimuth

As a result of the optimisation, the angle of tilt for the project site is 30°. Fig 3.2.2 and Table 3.2.1 shows the orientation parameters of the Project Site.

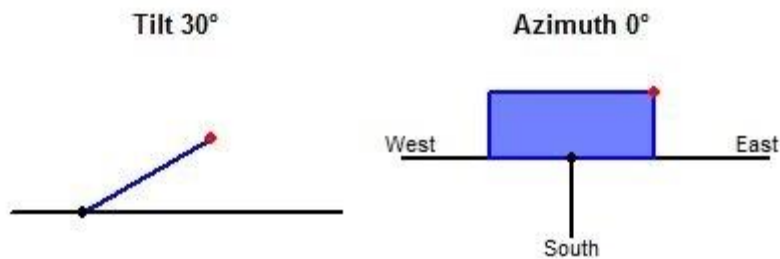


Fig. 3.2.2: Module tilt and Azimuth angles of the Project Site.

Table 3.2.1: Orientation parameters of the Project Site

Field type	Fixed tilted plane
Plane tilt	30 ⁰
Azimuth	0 ⁰

3.3 Horizon and Shading

3.3.1 Horizon & PVsyst

The far shadings are meant to act comprehensively on the PV plane. Acting comprehensively means that it would not give any fractional shading on the installation. The sun would either be or not be visible on the field. Horizon defining shadows would naturally consist of surrounding environment such as trees, buildings, mountains and are defined with a horizon line in PVsyst (illustrated in Fig. 3.3.1)

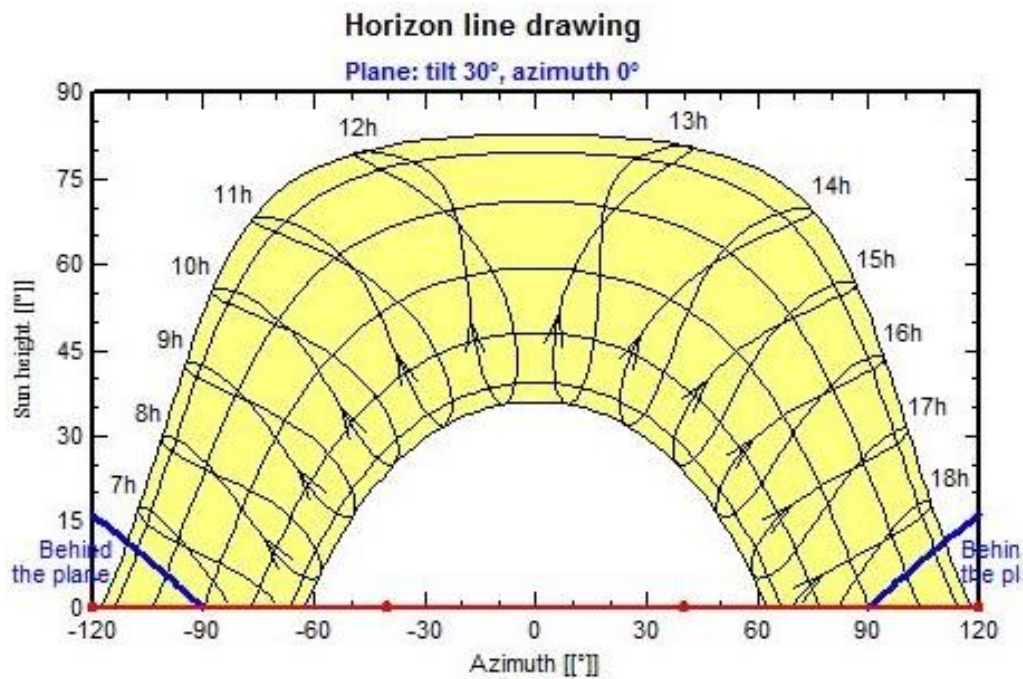


Fig. 3.3.1: Horizon line drawing in PVsyst for the project site

When a horizon line is accounted for in PVsyst the beam component of the irradiance is or is not visible on the field. PVsyst determines the exact time when the sun crosses the horizon line and weights the beam hourly value before performing the transposition. The diffuse part of the irradiance is assumed isotropic in the program. The diffuse part does, therefore, not depend on the position of the sun, it is the same irradiance which is coming from any direction of the sky and is therefore a constant factor during the year. The albedo contribution in PVsyst is considered to be linearly decreasing according to the horizon height. When using meteorological data from ground stations the horizon effect is already taken into account for that station. A comparison of the measuring station horizon with respect to the field horizon could be accounted for. Horizon line drawing in PVsyst for the project site is shown in Fig. 3.3.1. The site horizon is treated as free horizon.

3.3.2 Shade & its effects

Shade on the modules have a significant influence on the current produced in the cell and module due to reduction in irradiation on the cells. This is called irradiance deficit. The irradiance deficit induces a non-linear electrical loss. Shading is the worst enemy for power production. Even a shade of the size no bigger than human palm can effectively shut down the complete PV module. Shading can be classified into two types: soft shading and hard shading.

Soft shading can be defined as falling of the intensity of the irradiance levels, without creating any form of visible separation of shaded and unshaded regions. It's mainly cause due to clouds. Soft shading will lead to current output to drop proportionally. The voltage of the cell will remain unchanged provided that there is enough light ($\approx 50\text{W/m}^2$).

Hard shading, unlike soft shading, creates distinct visible separation of shaded and unshaded regions on the cell/module when any physical object, like a pole, tree or building etc. physically obstructs the sunlight. There will be some electric current till there exists a solid strip of illumination between two electrodes on a PV cell. The shadow shape does not affect the current much as it is proportional to the illuminated surface area of the cell. However, certain shading shapes can create narrow areas of illumination resulting current to be focused and congestion in the narrowly illuminated portions of the cell. This creates extremely high temperature, known as "hot spots" in these areas. Hot spots can cause burn-outs, damage the cell material and cause small fires within modules, as the current from the entire module gets strained into a very small area of solar cell. Shaded areas of the cell not only generates any currents but also reverses the characteristics in the cell and the stars behaving like a load which absorbs energy from the circuit.

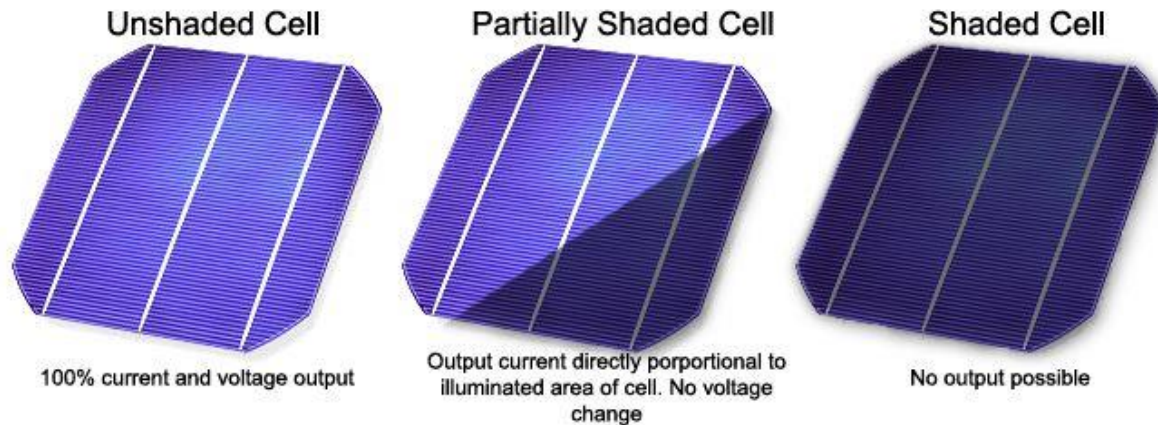


Fig. 3.3.2: Shading effect on voltage and current of cell. [29]

Electrical effects of hard shades and Soft shades can be better explained with help of their respective V-I and P-V curves. The V-I cures show in modules under Soft shades the current output is reduced and the output voltage remains unaffected, while under Hard shades the module output voltage is reduced and the output current remains intact. (See Fig. 3.3.3)

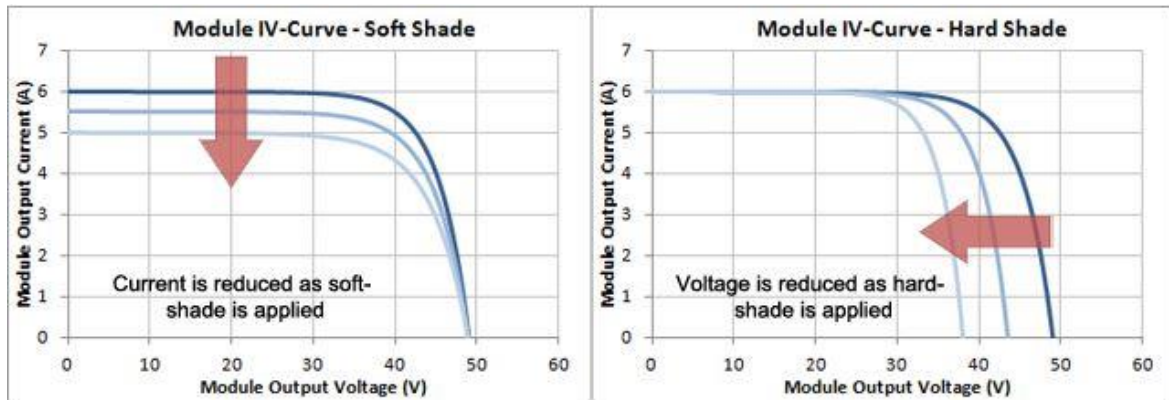


Fig. 3.3.3: V-I characteristics of modules under Soft and Hard shades. [30]

The P-V curves explain the power output and voltage profile of the modules under hard and soft shades (see Fig. 3.3.4). It indicates the shift of MPP under both shading conditions.

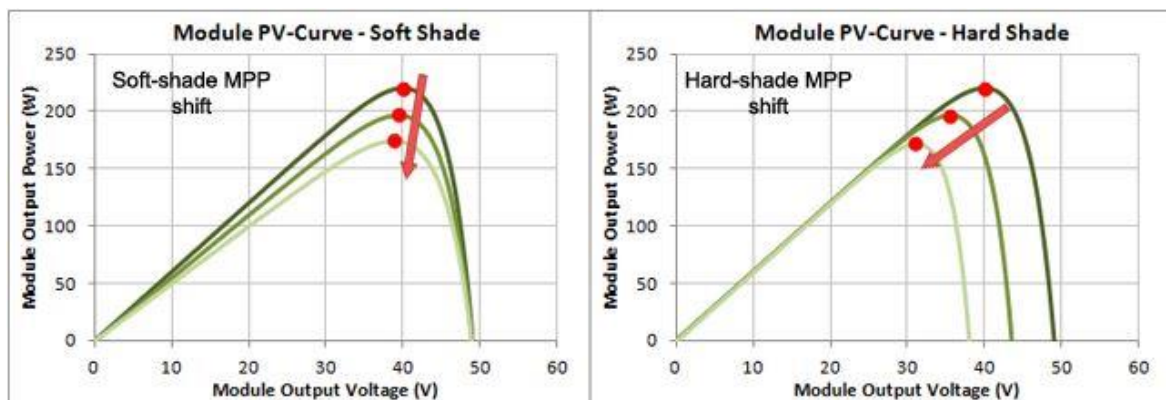


Fig. 3.3.4: P-V characteristics of modules under Soft and Hard shades. [31]

Factors affecting shading on the modules:

- latitude location
- Spacing between the strings
- String length
- Module height
- Tilt angle

The shadow cast by the first module onto the second when both kept in parallel and oriented towards the equator is governed by the equation 3.3.1 [32] and Fig. 3.3.3.

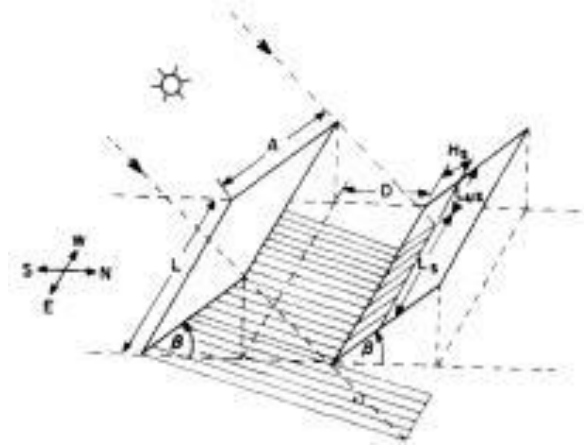


Fig. 3.3.5: shading of modules in rows [32]

$$H_s = A \left(1 - \frac{D + A \cos \beta}{A \cos \beta + A \sin \beta \cos \psi / \tan \alpha} \right) \quad (3.3.1)$$

Where H_s is the length onto the second module cast by the first, with a distance D between them, a tilt angle β , and a width of the modules A , on a given time marked by azimuth ψ and solar altitude α . Equation 3.3.1, can be solved for the distance D between the modules and $H_s = 0$ (no shading).

PVsyst and Shading

PVsyst offers detailed profiling of the shading effects under the near shadings tab. Shading factors define the fraction of PV field shading effectiveness. As the project site has no tall trees or buildings around causing hard shadows, so the effect of shading has been neglected.

3.4 System - Selecting Modules, Matching Array and Inverter

PVsyst offers options to select system main components: the module and inverter type and manufacturer from its database.

3.4.1 Selecting PV Module

There are many types of modules from which to choose. Mainly following types of technologies are available to choose from:

- Monocrystalline Silicon – orderly atomic structure, efficiency between 15-20%, space efficient but expensive.
- Multicrystalline Silicon – also called Polycrystalline silicon, less orderly cell structure, efficiency between 13-16%

- Amorphous Silicon – loose structure, low efficiency but least expensive.
- Ribbon-Drawn or Pulled Silicon – also made from multi Si, uses half amount of silicon than Poly-Si, efficiency between 13-14%.
- Thin Film Technology – easier and less costly to manufacture, not as efficient as other types but less susceptible to shading, better temperature coefficient.

Module selection should be done on the basis of specifications as Performance, Physical size, temperature coefficient, area of application and cost.

Considering the above said conditions, modules manufactured by *Canadian Solar Inc. (Model CS6X-320P)* have been selected for the proposed project. *CS6X-320P* modules have:

- High performance and energy yields[33]
 - Outstanding low irradiance performance of > 96%
 - Excellent module efficiency up to 16.68%
 - High energy yield at low NOCT = 45 °C
 - Positive power tolerance up to 5W
 - Reduced cell series resistance
- High modules quality[33]
 - Industry high PTC rating
 - 100% EL screening to eliminate product defects
 - IP67 junction box
- Robust module construction[33]
 - Enhanced 40 mm module frame
 - Enhanced 3.2 mm tempered glass
- Suitable for harsh environments[33]
 - Moisture permeability blocking

- Higher resistance to sand storms, salt-mist and ammonia
- Heavy snow load up to 5400 Pa
- Wind load up to 2400 Pa
- Insured 25-year performance warranty
- Various product and management certifications

Table 3.4.1 PV Module Specifications

Model	Canadian Solar Inc. CS6X-320P
STC Power	320 Wp
Technology	Silicon Poly Crystalline
Module size	0.982 x 1.954 m ²
No. of cells	1 x 72
Rough module area	1.92 m ²
Sensitive area of cells	1.75 m ²
Open circuit voltage V _{oc}	45.3 V
Max. power point voltage	36.8 V
Max. power P _{max}	319.8 W
Short circuit current I _{sc}	9.26 A
Max. power point current	8.69 A
Efficiency/module area	16.7 %
Temper. Coeff. of P _{max}	-0.41 %/ ⁰ C
Temper. Coeff. of V _{oc}	-0.31%/ ⁰ C
Temper. Coeff of I _{sc}	0.053%/ ⁰ C
Fill factor	0.762
Power tolerance	0~+5W
Operating temperature	-40 ⁰ C~+85 ⁰ C
Nominal cell operating temperature	45±2 ⁰ C
Maximum system voltage	1000V

Module Characteristics (*Canadian Solar Inc. CS6X-320P*)

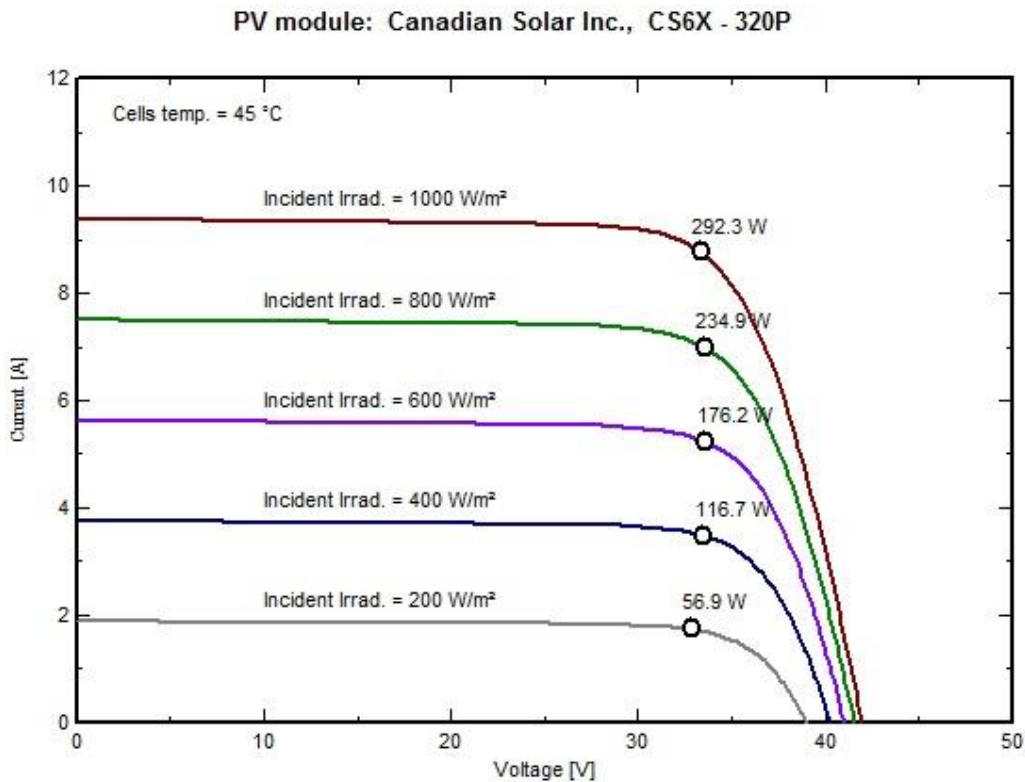


Fig. 3.4.1: Module V-I curve showing varying irradiance and constant temperature

Fig.3.4.1. shows that under constant module temperature, the current increases with increase in incident irradiance whereas the voltage is not much affected. Fig.3.4.2 illustrates that keeping incident irradiance constant, the voltage decreases with increase in module temperature, whereas the current nearly lies in very close range. Fig. 3.4.3 displays the module Power-Voltage curve under showing varying incident irradiance. It can be concluded from this curve that power output is proportional to the incident irradiance. The MPP represented by a white dot also shifts accordingly.

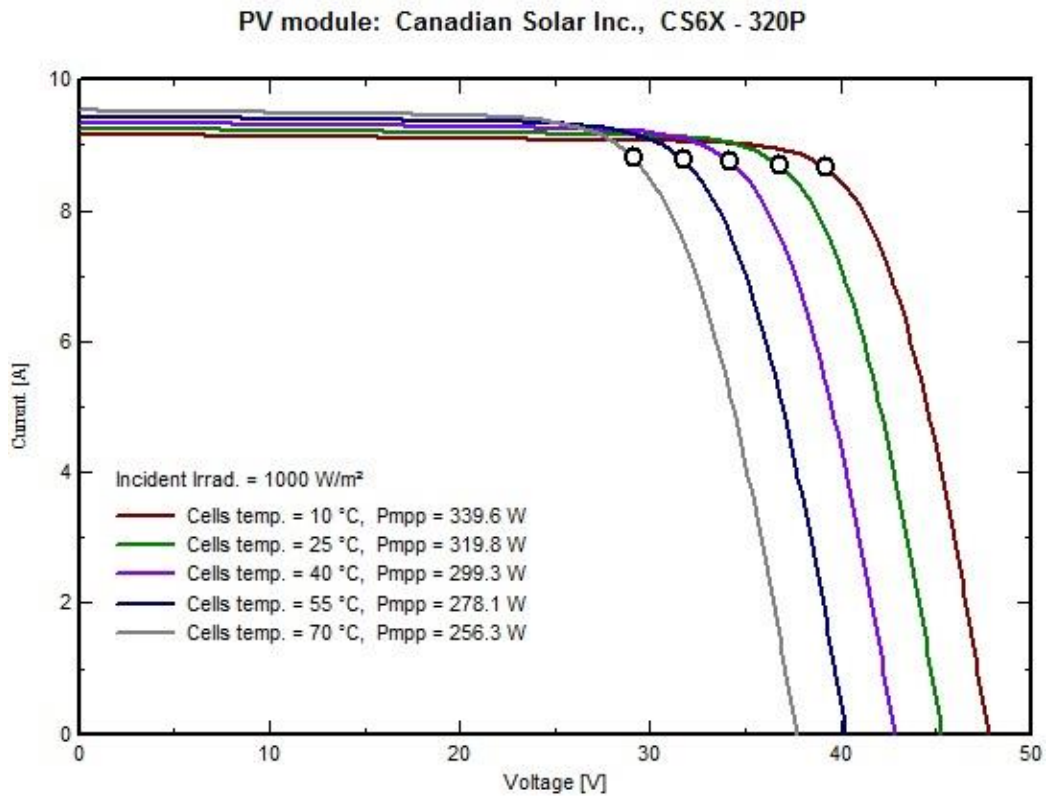


Fig. 3.4.2: Module V-I curve showing varying temperature and constant irradiance

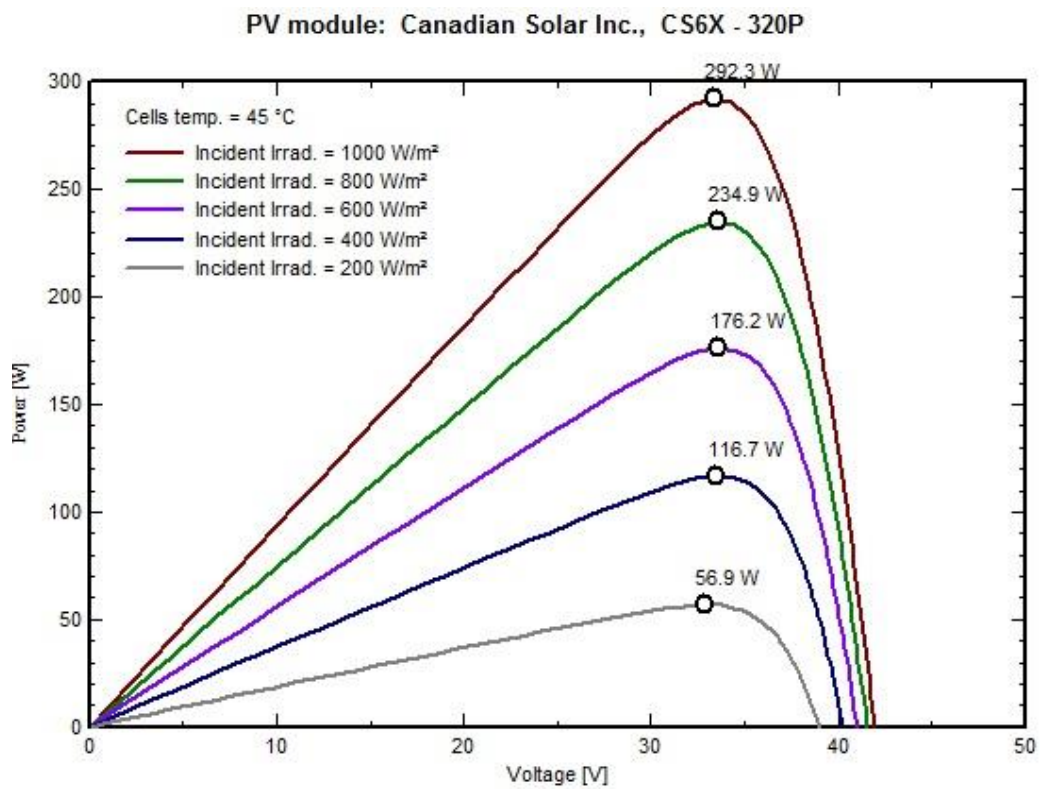


Fig. 3.4.3: Module P-V curve showing varying irradiance and constant temperature

PV module: Canadian Solar Inc., CS6X - 320P

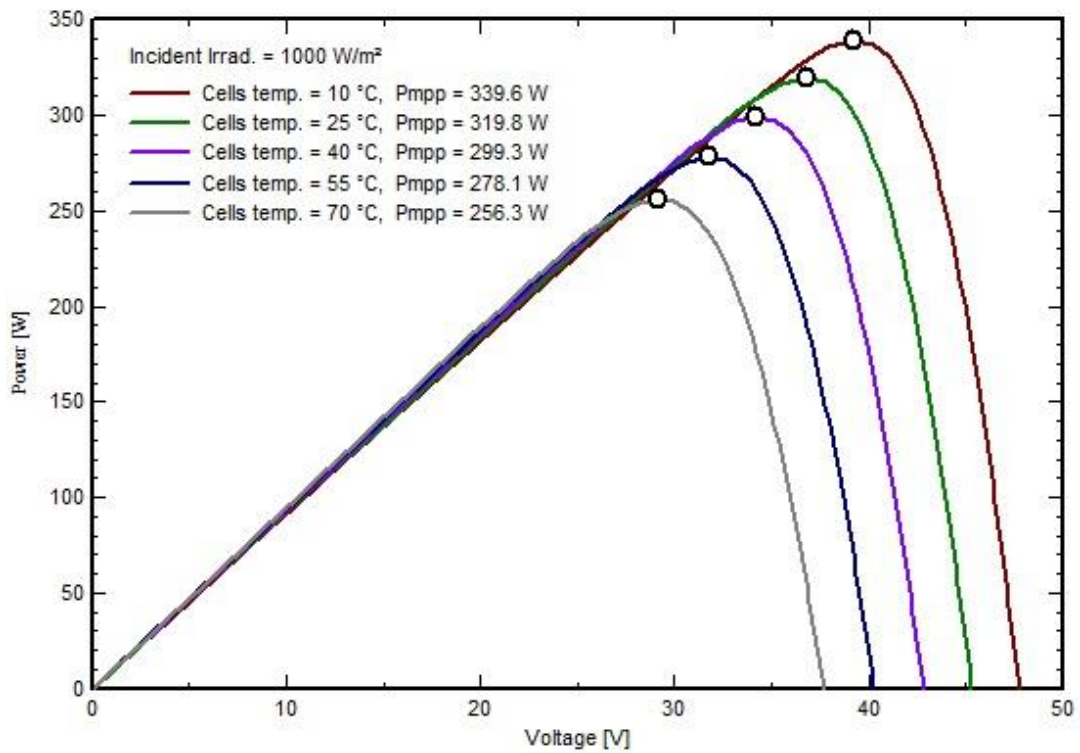


Fig. 3.4.4: Module P-V curve showing varying temperature and constant irradiance

PV module: Canadian Solar Inc., CS6X - 320P

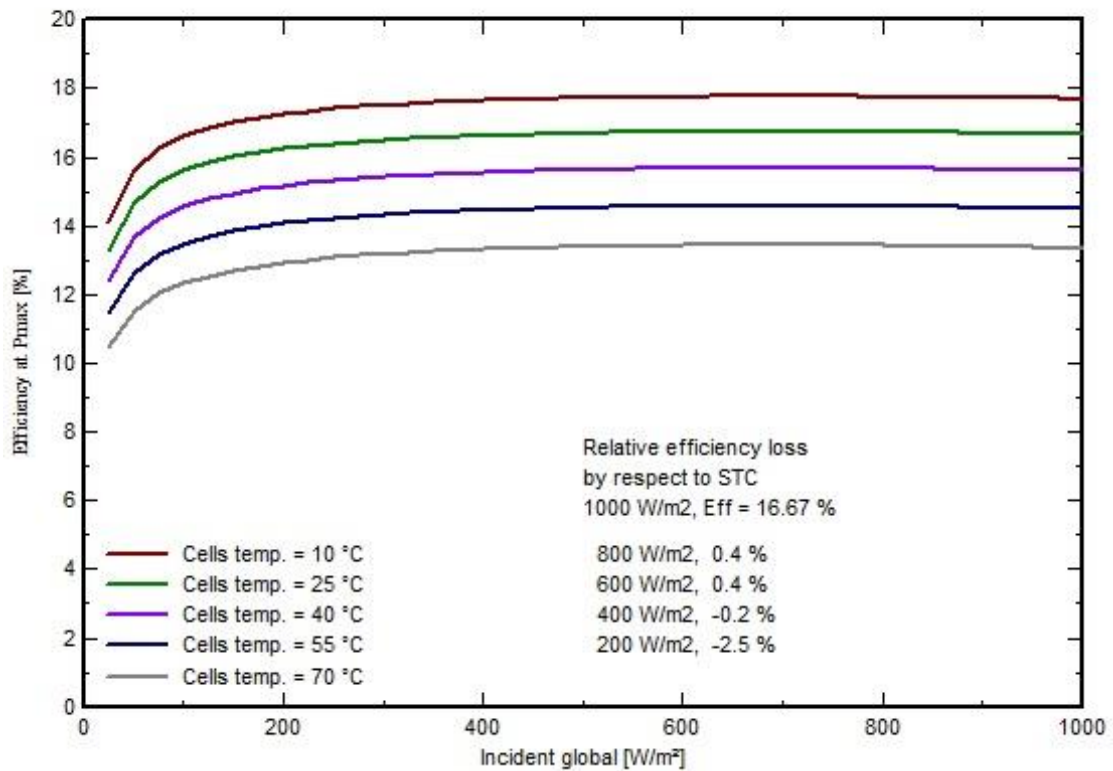


Fig. 3.4.5: Module efficiency - incident irradiance curve under varying temperature

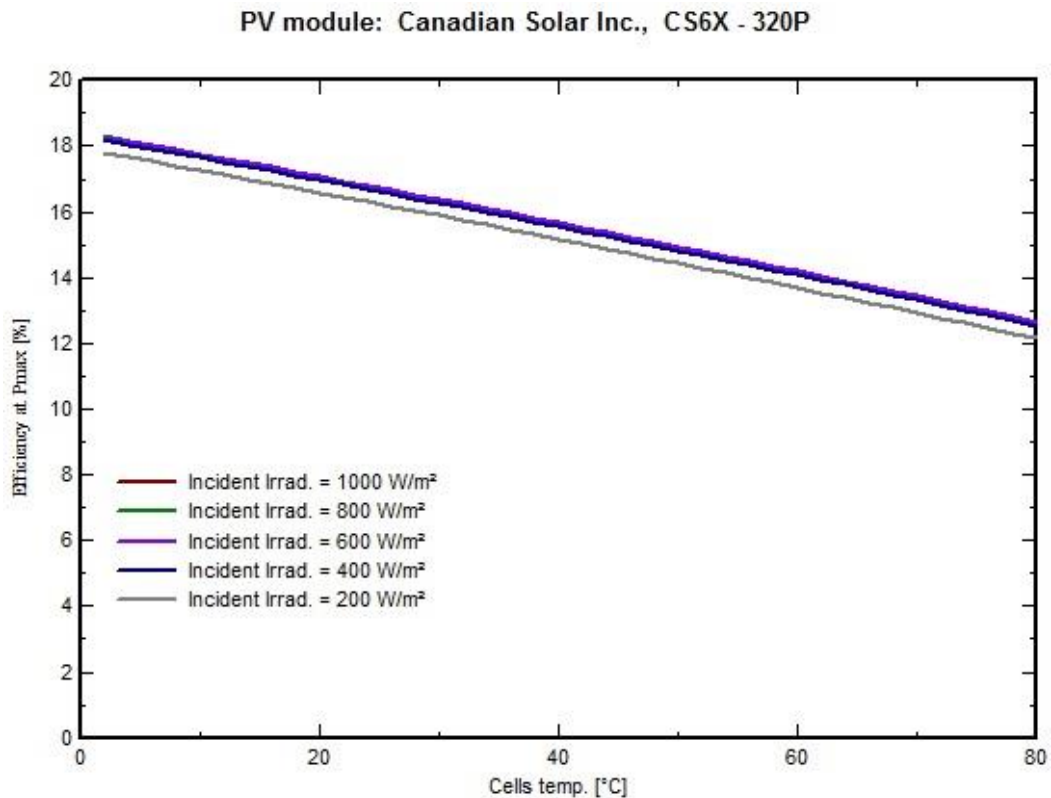


Fig. 3.4.6: Module efficiency - temperature curve under varying incident irradiance

Fig. 3.4.4 is a power-voltage curve under constant irradiance and varying temperature. It can be established from this curve that with increasing temperature, the MPP shifts downwards i.e. Power output decreases. Fig.3.4.5 demonstrates that the efficiency increases slightly with increasing irradiance at a particular temperature and with increasing temperature at a particular fixed level of irradiance, efficiency decreases (see Fig.3.4.6).

3.4.2 Inverter selection

Inverter being an important component of PV power plant should be chosen very carefully. A wide range of inverters are available in the market. The functions of the inverter has been explained in chapter 2 section 2.4. In a PV power plant, an inverter can be regarded as its heart. Inverters can be classified into:

- String Inverters
- Multistring Inverters
- Central Inverters
- Modular Inverters
- Three and Single phase Inverters
- Transformer or Transformer less Inverters

Inverter selection should be made keeping the following factors in account:

- Efficiency – inverters with high efficiency should be selected.
- Size of the power plant – string inverters for small plants and central inverters for large MW scale power plants are suitable.
- Shading – string inverters for sites with shading conditions.
- System availability – in case of faults or unavailability, in case of central inverters full capacity is lost as compared to string inverters where only a section of the system goes off.
- MPP range – inverters with wider range of MPP inculcate fore flexibility to System.

Inverter model *Sinvert 1000MS* manufactured by *Siemens* has been selected due to its high efficiency and single MPP.

Table 3.4.2: Inverter Specifications

Manufacturer	Siemens
Model	Sinvert 1000MS
Type	Central inverter
No. of Inverters	1
Input characteristics (PV Array side)	
Operating mode	MPPT
Minimum MPP voltage	450 V
Maximum MPP voltage	750 V
Absolute max. voltage for PV array	900 V
Nominal PV power	1041 kW
Maximum PV power	1116 kW
Power Threshold	5000 W
Output characteristics (Grid side)	
Nominal AC power	1000 kW _{ac}
Maximum AC power	1074 Kw
Nominal AC current	1443 A
Maximum AC current	1548 A
Maximum efficiency	96.5 %

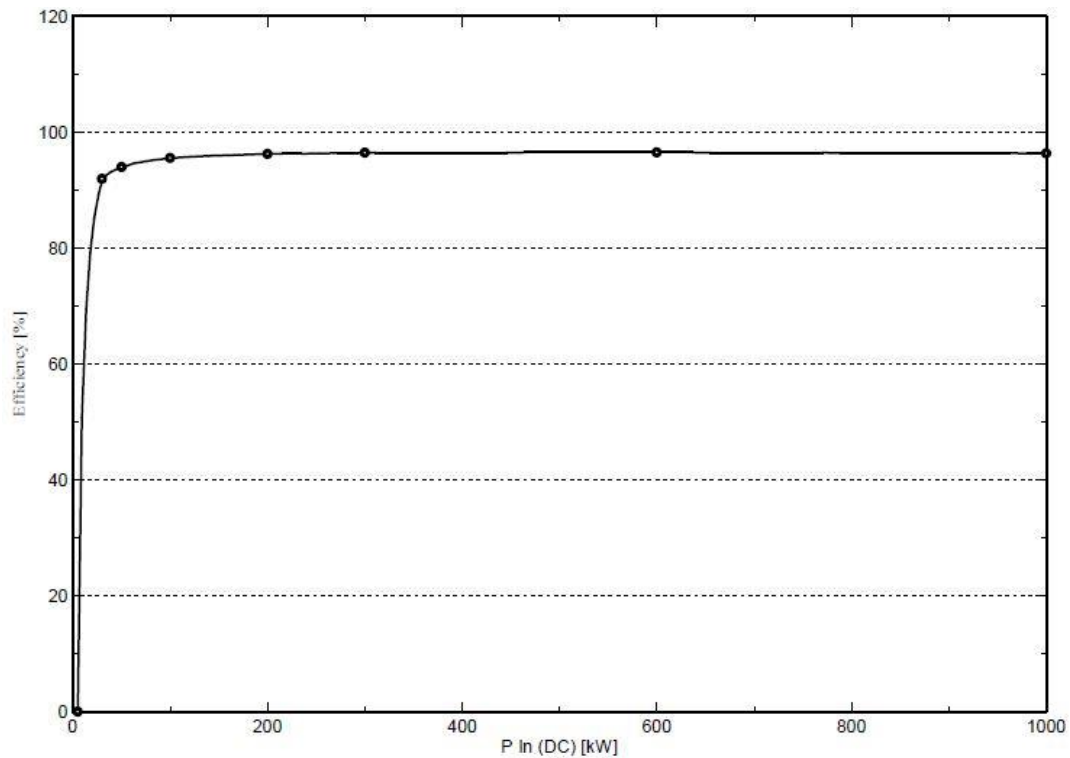


Fig. 3.4.7: Efficiency profile - input power of the selected inverter.

3.4.3 Array sizing & Matching Module and Inverter

In order to operate the system at its best and avoid mismatch losses, matching of voltage, current and power of the array and the inverter is must. Firstly, the array voltage should lie between the operating range voltages (MPPT range of voltage) of the inverter. Secondly, strings connected in parallel should be less than the maximum input current of the inverter. Thirdly, the no. of modules connected to the inverter is limited by the power output of the inverter. Fig. 3.4.8. shows the matching of the Array or inverter sizing in PVsyst, 15 Canadian Solar – CS6X 320P modules in series and 223 strings, using a Siemens - Sinvert 1000 MS, inverter.

Matching the PV array voltage to the voltage specifications of an inverter

The module voltage is temperature dependent. The winter and summer extreme temperatures are used, while matching arrays with inverters, in order to determine the string sizing in terms of number of modules. The maximum cell temperature is used for determining the minimum amount of modules in a string. The minimum number of modules in a string is given by the equation.3.4.1

$$N_{min} = \frac{V_{MPP \text{ inverter min}}}{V_{MPP \text{ module max. temp}}} \quad (3.4.1)$$

$$\text{where } V_{MPP \text{ module max. temp}} = V_{MPP \text{ STC}} \cdot \left(1 + \Delta T \cdot \frac{\gamma_{VMPP}}{100}\right) \quad (3.4.2)$$

Where $V_{MPP \text{ inverter min}}$ is the minimum inverter voltage at MPP, $V_{MPP \text{ module max. temp}}$ is the MPP voltage of the module at maximum temperature, $V_{MPP \text{ STC}}$ is the MPP voltage under STC conditions, ΔT is the temperature difference between the STC temperature and the highest module or cell temperature, and where γ_{VMPP} is the voltage temperature coefficient of the module.[34]

Maximum number of modules in series is given by the equation 3.4.3

$$N_{max} = \frac{V_{max \text{ inverter}}}{V_{oc \text{ module min temp}}} \quad (3.4.3)$$

$$\text{Where, } V_{oc \text{ module min temp}} = V_{oc \text{ STC}} - \left(\frac{\gamma_{Voc}}{100} \cdot V_{oc} \cdot \Delta T\right) \quad (3.4.4)$$

$V_{max \text{ inverter}}$ is the maximum inverter voltage, $V_{oc \text{ module min temp}}$ is the open circuit voltage of the module at minimum temperature, $V_{oc \text{ STC}}$ is the open circuit voltage at STC conditions. γ_{Voc} is the open circuit temperature coefficient of the module (in V/°C) and ΔT is the temperature difference between the STC and the lowest cell (or module) temperature. [34]

Matching Array current to the current specifications of an inverter

Number of strings in parallel is given by the equation 3.4.5

$$N_{strings \text{ in parallell}} = \frac{I_{max \text{ inverter input}}}{I_{sc \text{ STC}} + (\gamma_{Isc} \cdot \Delta T)} \quad (3.4.5)$$

Where $I_{max \text{ inverter input}}$ is the maximum input current to the inverter, $I_{sc \text{ STC}}$ is the short circuit current under STC, γ_{Isc} is the short circuit current temperature coefficient of the module in A/°C, and ΔT is the temperature difference between the STC and the highest cell (or module) temperature. [34]

Matching Array power to the power specifications of an inverter

The parameters like maximum DC input power and PV array rated power are included in the specifications of the inverter. The inverter maximum DC input power represented by dotted line in Figure 3.4.8, is the maximum quantity of DC power that the inverter can convert to AC. The inverter maximum DC input power should be less than the maximum PV array power. Fig. 3.4.9 shows power sizing: Inverter output distribution

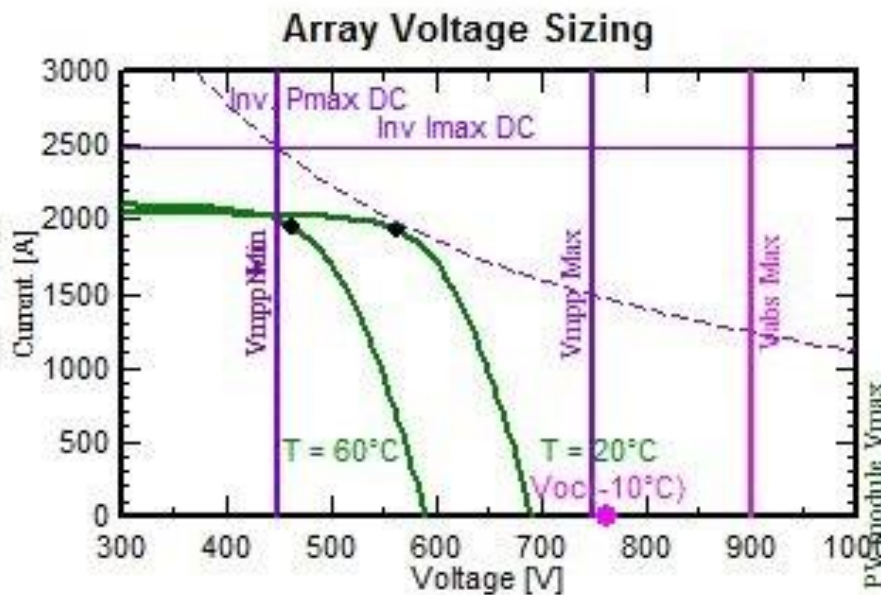


Fig. 3.4.8: shows the matching of the Array or inverter sizing in PVsyst, 15 Canadian Solar – CS6X 320P modules in series and 223 strings, using a Siemens - Sinvert 1000 MS, inverter

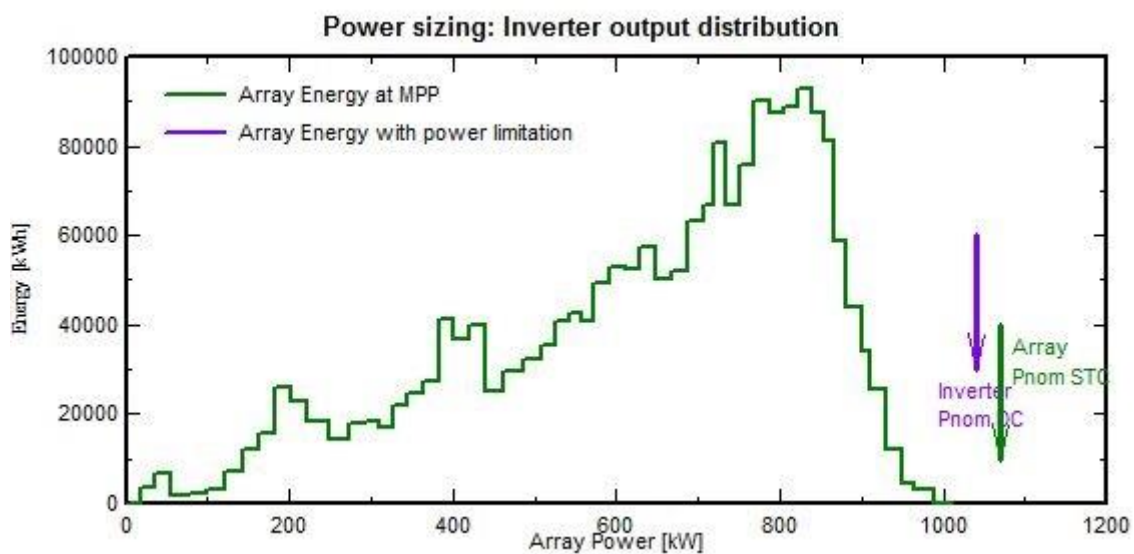


Fig. 3.4.9: Power sizing showing Inverter output distribution

PV_{sys} does the array sizing and matching with the inverter.

Table 3.4.3: Array Sizing and Operating Conditions

No. of modules in series	15 modules
No. of modules in parallel	223 strings
Total no. of modules	3345
Unit nominal power	320 W _p
Array global power (Nominal STC)	1070 kW _p
Array Global power (operating conditions)	954 kW _p (50 ⁰ C)
Array Voltage V _{MPP}	488 V
Array current I _{MPP}	1955 A

3.4.4 Operating conditions of SPV power plant

Table 3.4.4 Operating conditions of SPV power plant

V _{MPP} (60 ⁰ C)	463 V
V _{MPP} (20 ⁰ C)	564V
V _{OC} (-10 ⁰ C)	764 V
For plane Irradiance 1000 W/m ²	
I _{MPP} (STC)	1955A
I _{SC} (STC)	2098 A
Max. Operating power at 1000 W/m ² & 50 ⁰ C	954 kW
Array Nominal Power (STC)	1070

3.5 Losses

Losses occurring in the PV system can be defined as the reduction of the output energy of the module/ array with respect to nominal power of the module at STC. PV_{sys} considers losses such as Ohmic losses, thermal parameter, module quality - LID mismatch, soiling loss, IAM loss while simulating the system.

Thermal losses

The thermal losses account for the loss due to the temperature difference between temperature at STC conditions and the modules. The modules operate at temperatures (60 -70⁰ C) normally

much higher than (STC) at 25° C. PVsyst uses the single diode model for calculating the thermal loss (as explained in Section 2.2).

PVsyst gives two options for calculating the thermal loss, either by the standard NOCT coefficient, or by defining the field thermal loss factor. The program treats both methods at par. The thermal behaviour is defined by a thermal loss factor designated by U-value. U-value is further split into a factor proportional to the wind velocity U_V and a constant component U_C [35]:

$$U = U_C + U_V \cdot v \quad (3.5.1)$$

Where U is in $[\text{W}/\text{m}^2 \cdot \text{k}]$, v = wind velocity in $[\text{m}/\text{s}]$.

These factors are influenced by the type of the mounting of modules (ground mounted, sheds, rooftop, etc.). Default values for these factors can be set depending upon the mounting type categorised into:

- Integration with fully insulated back.
- Semi-integrated with air duct behind.
- Free mounted module with air circulation.

The NOCT coefficient standard can also be used for determining the thermal losses instead thermal loss factor. The manufacturers specify the NOCT coefficient.

For this project, thermal loss factor is used to assess the thermal losses. Default values for the U-value has been chosen under the category of free mounted module with air circulation and the wind factor has been neglected.

Ohmic losses

PVsyst takes into account the losses due to wiring resistance (I^2R losses) at STC. The global wiring resistance of the DC circuit can be set or a detailed computation of the same can be performed, or the Ohmic loss fraction at STC can be set. In this case the Ohmic loss fraction at STC of 1.5 % is chosen.

Module Quality – LID – Mismatch Losses

Module Quality

Module efficiency specified by the manufactures may vary with actual conditions. The loss incurred due to this module quality mismatch can cause a great uncertainty when assessing PV system performance. The module efficiency loss default is -0.4 % (negative value indicates

over performance).

LID – Light Induced Degradation Losses

PV modules tend to degrade with time due to exposure to sunlight. As a result loss of performance takes place, with crystalline modules. This is termed as Light Induced Degradation (LID) loss. The LID loss is associated to the superiority of the wafer manufacturing. . In this case the LID loss has been neglected.

Mismatch Losses

In actual, the modules in an array may not perform at same characteristics. There can be a possibility of mismatch of parameters in an array accounting to mismatch losses. PVsyst offers a detailed computation of the mismatch losses and default value of 1% loss at MPP or 2.5% loss when running at fixed voltage can be selected. In this case, as the operation is using MPPT, a default value of 1% loss at MPP is selected.

Soiling loss

Accumulation of suspended particles or dust due to pollution may affect the system performance depending on the environment of the system. Soiling can be deemed as mismatch losses as some cells get shaded resulting in irradiance loss and, therefore, give abnormal I-V characteristics. The soiling loss is expressed as a percentage of the STC power. In PVsyst, yearly soiling loss factor can be selected or monthly values can be defined. In this case, soiling loss has been neglected as provision of cleaning the modules can be made.

Incidence angle modifier (IAM) losses

Solar energy conversion in modules is subjected to optical losses. These losses are significantly depending on light incidence angle to the plane of module. These losses are termed as Incidence Angle Modifier (IAM) losses or reflection losses. It is an optical effect which take place when the irradiation reaches the glass protecting the PV cells lying underneath. IAM losses are accounted in PVsyst as per the equation 3.5.2.

$$IAM = 1 - b_0 \left(\frac{1}{\cos i} - 1 \right) \quad (3.5.2)$$

Where i is the incidence angle on the module plane. Equation 3.4.9 is as per the Fresnel laws & uses ASHRAE model parameter b_0 . The default value for b_0 is 0.05 (for crystalline PV modules). [36]

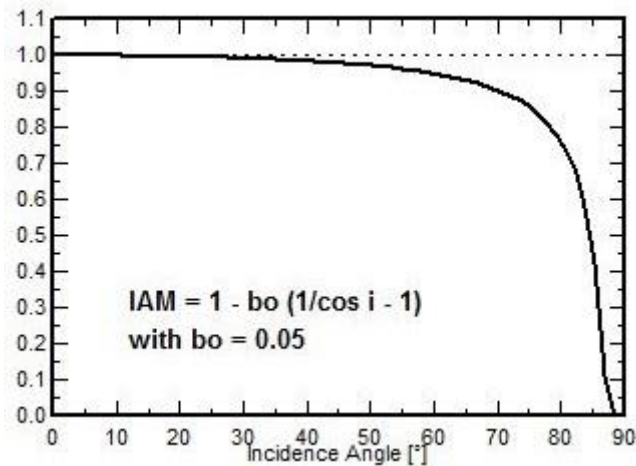


Fig. 3.5.1: Incidence Angle Modifier

PVsyst also has a provision for accounting the power loss incurred on account of Auxiliaries like fans, lighting, air conditioning or appliances installed at plant site which consume power and Unavailability – which accounts for generation power loss due to faults, failures and maintenance. In case of this project, both these factors have been neglected. PVsyst has a unique feature that it generates the detailed system loss diagram.

3.6 Performance Ratio

Performance ratio (PR) is also called the quality factor of a solar power plant. It is a measure of quality of a solar power plant and is expressed as a percentage. PR is the ratio of actual energy output to the theoretical calculated value of energy output of the PV system. Mathematically,

$$PR = \frac{Y_f}{Y_r} \quad (3.6.1)$$

Where Y_f is the final system yield and Y_r is the reference yield. The reference yield is the system yield without considering losses, whereas the final system yield is calculate considering the losses in the system. The PR is an indicator for the overall influence of losses. PR is a measure of actual energy available for injection to grid after considering losses. The PR gives the information about the energy efficiency and reliability of the plant. High performance plants can have a performance ratio to the tune of 80%.

3.7 Cable sizing

Cable sizing is indirectly taken into account in PVsyst while specifying the ohmic losses in the system. The cable should be sized such that it could operate continuously under full load conditions at a suitable voltage, without considerable voltage drop and withstand the worst short circuit currents flowing through it. Factors to be taken into account for cable sizing:

- The Current Carrying Capacity (CCC)
- Economic considerations
- Practical considerations
- Voltage loss
- Aesthetic consideration

The CCC is the maximum current a conductor can withstand damaging itself in worst conditions. The CCC is influenced by type of insulation, the area of cross-section of the conductor, and the environment around the installed cable. The minimum cross section size of the cable can be calculated with the Equation 3.7.1

$$A_{DC\ cable} = \frac{2 \cdot L_{DC\ cable} \cdot I_{DC} \cdot \rho}{Loss \cdot V_{MPP\ string}} \quad (3.7.1)$$

Where

$L_{DC\ cable}$ is the route length of the DC cable.

I_{DC} is the string current.

ρ is the resistivity of the wire.

$Loss$ is the percentage of maximum voltage loss in the conductor.

$V_{MPP\ string}$ is the string voltage.

The route length of the DC cable is adjusted for with the factor of 2, since this is closer to the total circuit wire length.

ECONOMIC EVALUATION

A simple overview of the economic aspects PV system installed is done to get an idea of the costs involved. The approximate costs of various system components and services has been accounted to calculate the amount of investment required. Also the yearly running costs required have been considered. Taxing, subsidies and Financing of the project keeping in mind the term and interest rate have been carried out. Taxes are nil as the Indian government offers tax exemptions over the modules, inverters and other components in order to encourage the solar power in the country. Also the earnings from the sale of power from the PV plants are exempted from tax. Subsidies have been neglected in the evaluation. A loan duration of 10 years at an interest rate of 12% per annum has been considered. The cost of energy production per unit (kWh) will be calculated in chapter 5.

PVsyst offers a comprehensive evaluation of the PV plant economics. As stated above, the economic evaluation involves detailed list of various factors like capital cost, running costs, financing, taxes and subsidies, period of loan and rate of interest. PVsyst calculates the cost of energy per kWh and specific investment. PVsyst presents the economic analysis in form of graphs showing yearly financial balance, yearly cumulative balance and a table of long term economic balance over the lifetime of the plant i.e.25 years. The economic evaluation can help the investor in decision making. All effort has been taken to contact manufacturers of modules and inverters and other components in order to use the most current prices of the components in the evaluation to give the most realistic picture of the price situation per now. However, such prices could change with time and would only be valid for the time when or if such a request was to be answered. Details of the costs are given in Table 4.1.1.

4.1 Costs of different components and associated services

Table 4.1.1: Detailed cost analysis of SPV power plant [36]

Cost of each module	₹ 11110
Total cost of modules supply, installation, erection & commissioning	₹ 37162950
Inverter installation, erection & commissioning	₹ 6000000
Module mounting structure and its civil works	₹ 4000000
Cables & related civil works	₹ 4000000
HT panel & related civil works	₹ 1500000
Transformer, its testing & commissioning	₹ 1800000
Isolators, meters with CT & PT, switchyard related works	₹ 1800000
Control panel, ACDB, DCDB, batteries with chargers	₹ 800000
Weather monitoring station, Earthling & Lightening protection and SCADA	₹ 2500000
Control room, boundary wall & other civil works	₹ 3000000
String combiner boxes	₹ 1200000
Engineering & miscellaneous expenses	₹ 1500000
Insurance	₹ 900000
Net investment	₹ 66162950
Annual maintenance cost & land rent	₹ 1000000
Period of loan	10 years
Rate of interest	12 %
Depreciation rate per year	1%

4.2 Tariff

The PSERC (Punjab Electricity Regulatory Commission) on 24th July 2015 has finalized the tariff for Solar Energy as ₹ 7.04 / kWh [37]. The PSPCL (Punjab State Electricity Power Corporation) has renewable energy purchase obligations put up by the PSERC.

SIMULATION & RESULTS

5.1 Simulation settings

5.1.1 Orientation

Field type: fixed tilted plane

Plane tilt: 30°

Azimuth: 0°

5.1.2 Loss Parameters

Constant loss factor U_C : 29.0 W/m²k

Wind loss factor U_V : 0.0 W/m²k/m/s

Ohmic losses parameters (DC Circuit)

Global wiring resistance: 225 mΩ

Or loss fraction at STC: 1.5 %

Voltage drop across series diode: 0 V

Module Quality – LID – Mismatch parameters

Module quality

Module efficiency loss: -0.4 %

LID (Light Induced Degradation)

LID loss factor: 0.0 %

Mismatch losses

Power loss at MPP: 1.0 %

Loss when running at fixed voltage: 2.5 %

Soiling losses parameters

Yearly soiling loss factor: 0.0 %

IAM loss parameter

Incidence angle effect

As per ASHRAE model: $b_0 = 0.05$

Auxiliaries energy losses: 0.0%

Unavailability of the system: Undefined (0)

5.1.3 Horizon parameters: Free Horizon

Table 5.1.3: Horizon points

Height [°]	0.0	0.0	0.0	0.0
Azimuth [°]	-120	-40	40	120

Diffuse factor

Horizontal Diffuse factor: 1.00

Tilted Plane attenuation factors

Diffuse factor 1.00

Albedo factor 1.00

5.1.4 Shadings: No Shadings

5.1.5 Economic evaluation parameters

Taxes: 0.00% [NIL]

Subsidies: 0.00% [NIL]

Loan

Period: 10 years

Rate of interest: 12 % p.a.

Annuity factor: 17.70 %cap/year

Feed - in tariff: ₹ 7.04/kWh

Life span of project: 25 years

5.1.6 Power factor (for grid injection): 1.00

5.2 RESULTS: In Tabular form.

Table 5.2.1: System production

Produced energy	1918 MWh/year
Specific production	1792 kWh/kWp/year
Performance ratio (PR)	84.2 %
Normalised production	4.91 kWh/kWp/day
Array losses	0.74 kWh/kWp/day
System losses	0.18 kWh/kWp/day

Table 5.2.2: Meteo. and incident energy

	GlobHor	DiffHor	T Amb	GlobInc	DifSInc	Alb Inc
	kWh/m ²	kWh/m ²	°C	kWh/m ²	kWh/m ²	kWh/m ²
January	106.3	29.76	11.10	161.2	38.74	1.425
February	122.6	32.20	14.20	167.2	39.95	1.643
March	164.9	46.81	20.60	195.7	53.10	2.210
April	184.5	56.40	27.10	192.4	59.36	2.470
May	200.9	67.58	31.30	188.5	66.64	2.678
June	195.6	69.60	33.00	175.8	66.58	2.607
July	180.7	74.09	30.80	166.0	71.14	2.408
August	171.7	66.96	29.30	171.5	67.63	2.297
September	159.3	51.60	27.90	179.6	56.92	2.134
October	147.6	38.13	23.90	193.0	47.27	1.977
November	118.2	27.00	18.50	177.0	36.17	1.584
December	101.1	26.35	13.09	161.3	35.95	1.354
Year	1853.5	586.48	23.44	2129.2	639.45	24.787

Table 5.2.3: Simulation main results

	GlobHor kWh/m ²	T Amb °C	GlobInc kWh/m ²	GlobEff kWh/m ²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %	PR %
January	106.3	11.10	161.2	157.5	160661	154860	15.53	14.97	89.7
February	122.6	14.20	167.2	163.6	162919	156997	15.18	14.63	87.7
March	164.9	20.60	195.7	190.9	184205	177553	14.66	14.13	84.7
April	184.5	27.10	192.4	187.2	175359	168974	14.20	13.68	82.0
May	200.9	31.30	188.5	182.9	168986	162858	13.97	13.46	80.7
June	195.6	33.00	175.8	170.3	157576	151872	13.96	13.46	80.7
July	180.7	30.80	166.0	160.6	151164	145667	14.19	13.67	82.0
August	171.7	29.30	171.5	166.5	157094	151325	14.27	13.75	82.5
September	159.3	27.90	179.6	174.8	164762	158833	14.30	13.78	82.6
October	147.6	23.90	193.0	188.6	179584	173113	14.50	13.97	83.8
November	118.2	18.50	177.0	173.2	169031	162904	14.88	14.34	86.0
December	101.1	13.09	161.3	157.7	159121	153333	15.37	14.81	88.8
Year	1853.5	23.44	2129.2	2073.9	1990460	1918288	14.56	14.04	84.2

Legends: GlobHor: Horizontal global irradiance, T Amb: Ambient Temperature, GlobInc: Global incident coll. Plane,
 GlobEff: Effective Global, corr. for IAM & shadings, EArray: Effective energy at the output of Array, E_grid: Energy injected into the grid,
 EffArrR: Effic. Eout Array/ rough area, EffSysR: Effic. Eout System/ rough area, PR: performance ratio.

Table 5.2.4: Effective incident energy (Transposition, IAM Shadings)

	GlobHor kWh/m ²	GlobInc kWh/m ²	GlobIAM kWh/m ²	GlobEff kWh/m ²	DiffEff kWh/m ²
January	106.3	161.2	157.5	157.5	37.16
February	122.6	167.2	163.6	163.6	38.40
March	164.9	195.7	190.9	190.9	50.99
April	184.5	192.4	187.2	187.2	57.00
May	200.9	188.5	182.9	182.9	64.06
June	195.6	175.8	170.3	170.3	63.92
July	180.7	166.0	160.6	160.6	68.34
August	171.7	171.5	166.5	166.5	65.01
September	159.3	179.6	174.8	174.8	54.59
October	147.6	193.0	188.6	188.6	45.42
November	118.2	177.0	173.2	173.2	34.75
December	101.1	161.3	157.7	157.7	34.52
Year	1853.5	2129.2	2073.9	2073.9	614.14

Table 5.2.5: Optical factors

	GlobHor kWh/m ²	GlobInc kWh/m ²	FTransp	FIAMBm	FIAMGI	FIAMShd
January	106.3	161.2	1.516	0.984	0.977	0.977
February	122.6	167.2	1.363	0.984	0.978	0.978
March	164.9	195.7	1.187	0.982	0.975	0.975
April	184.5	192.4	1.043	0.980	0.973	0.973
May	200.9	188.5	0.938	0.977	0.971	0.971
June	195.6	175.8	0.899	0.974	0.968	0.968
July	180.7	166.0	0.919	0.974	0.968	0.968
August	171.7	171.5	0.998	0.979	0.971	0.971
September	159.3	179.6	1.127	0.982	0.974	0.974
October	147.6	193.0	1.308	0.984	0.977	0.977
November	118.2	177.0	1.497	0.985	0.979	0.979
December	101.1	161.3	1.596	0.984	0.978	0.978
Year	1853.5	2129.2	1.149	0.981	0.974	0.974

Table 5.2.6: Detailed system losses

	ModQual	MisLoss	OhmLoss	EArrMPP	InvLoss
	kWh	kWh	kWh	kWh	kWh
January	-653	1640	1658	160661	5801
February	-663	1665	1869	162919	5921
March	-750	1883	2216	184205	6651
April	-714	1792	2096	175361	6387
May	-688	1726	1904	168988	6130
June	-641	1609	1682	157580	5708
July	-614	1542	1507	151164	5497
August	-639	1604	1680	157094	5769
September	-671	1684	1912	164762	5929
October	-731	1836	2167	179584	6471
November	-688	1727	1985	169031	6127
December	-647	1624	1652	159121	5788
Year	-8100	20331	22328	1990469	72180

Table 5.2.7: Detailed inverter losses

	EOutInv	EffInvR	InvLoss	IL Oper	IL Pmin	IL Pmax	IL Vmin	IL Vmax
	kWh	%	kWh	kWh	kWh	kWh	kWh	kWh
January	154860	96.4	5801	5801	0	0	0.000	0
February	156997	96.4	5921	5921	0	0	0.000	0
March	177553	96.4	6651	6651	0	0	0.000	0
April	168974	96.4	6387	6385	0	0	1.715	0
May	162858	96.4	6130	6128	0	0	2.433	0
June	151872	96.4	5708	5704	0	0	4.215	0
July	145667	96.4	5497	5497	0	0	0.000	0
August	151325	96.3	5769	5769	0	0	0.000	0
September	158833	96.4	5929	5929	0	0	0.023	0
October	173113	96.4	6471	6471	0	0	0.000	0
November	162904	96.4	6127	6127	0	0	0.000	0
December	153333	96.4	5788	5788	0	0	0.000	0
Year	1918288	96.4	72180	72172	0	0	8.387	0

Table 5.2.8: Performance Ratio and Energy injected to grid (E_Grid)

	PR	E_Grid kWh
January	0.897	154860
February	0.877	156997
March	0.847	177553
April	0.820	168974
May	0.807	162858
June	0.807	151872
July	0.820	145667
August	0.825	151325
September	0.826	158833
October	0.838	173113
November	0.860	162904
December	0.888	153333
Year	0.842	1918288

Table 5.2.9: Normalised Performance coefficients

	Yr kWh/m ² .day	Lc	Ya kWh/kWp/d	Ls	Yf kWh/kWp/d	Lcr	Lsr	PR
January	5.20	0.358	4.84	0.175	4.67	0.069	0.034	0.897
February	5.97	0.536	5.44	0.198	5.24	0.090	0.033	0.877
March	6.31	0.763	5.55	0.200	5.35	0.121	0.032	0.847
April	6.41	0.953	5.46	0.199	5.26	0.149	0.031	0.820
May	6.08	0.988	5.09	0.185	4.91	0.162	0.030	0.807
June	5.86	0.954	4.91	0.178	4.73	0.163	0.030	0.807
July	5.36	0.800	4.56	0.166	4.39	0.149	0.031	0.820
August	5.53	0.797	4.73	0.174	4.56	0.144	0.031	0.825
September	5.99	0.854	5.13	0.185	4.95	0.143	0.031	0.826
October	6.23	0.814	5.41	0.195	5.22	0.131	0.031	0.838
November	5.90	0.635	5.26	0.191	5.07	0.108	0.032	0.860
December	5.20	0.408	4.80	0.174	4.62	0.078	0.034	0.888
Year	5.83	0.739	5.09	0.185	4.91	0.127	0.032	0.842

Table 5.2.10: Monthly hourly averages for E_Grid (kW)

	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H
January	0	0	213	458	635	733	761	729	655	502	286	23	0
February	0	11	255	490	667	781	818	806	708	561	362	148	0
March	0	93	303	505	667	764	801	765	694	566	394	173	2
April	5	152	355	533	671	737	753	725	649	519	360	164	9
May	29	170	353	522	641	676	697	647	575	469	305	141	29
June	35	152	319	470	588	645	657	634	579	473	320	158	33
July	30	131	284	437	549	597	618	593	537	431	301	155	35
August	10	122	283	431	555	633	658	642	585	469	322	150	22
September	0	138	329	496	617	709	738	712	622	498	311	124	1
October	0	152	370	562	714	798	805	742	641	480	270	51	0
November	0	76	340	565	720	802	813	767	651	467	226	4	0
December	0	8	259	495	655	748	773	727	613	446	219	2	0
Year	9	101	305	497	640	718	740	707	625	490	306	107	11

Table 5.2.11: Monthly hourly maximum values for E_Grid (kW)

	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H
January	0	5	281	537	734	847	879	851	780	634	389	143	0
February	0	28	306	571	765	876	919	908	828	680	462	202	0
March	0	144	376	620	797	892	930	904	815	671	497	225	22
April	25	184	414	619	772	855	893	865	773	632	432	196	30
May	38	199	415	610	730	785	806	772	680	554	382	183	42
June	48	186	383	585	702	761	786	751	676	552	375	198	48
July	46	164	370	542	709	761	789	761	688	578	400	206	53
August	28	157	372	567	752	802	840	836	713	575	420	204	40
September	0	170	408	618	775	849	871	880	779	623	405	181	9
October	0	183	438	647	783	857	856	808	710	542	328	109	0
November	0	148	391	622	771	845	869	809	701	510	259	21	0
December	0	27	312	579	743	828	846	801	703	531	276	18	0
Year	48	199	438	647	797	892	930	908	828	680	497	225	53

Table 5.2.12: Monthly hourly minimum values for E_Grid (kW)

	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H
January	0	0	86	194	240	338	357	375	312	266	95	0	0
February	0	0	126	41	407	555	508	512	227	205	33	13	0
March	0	0	97	162	246	324	382	357	332	275	190	82	0
April	0	100	206	304	391	487	488	502	438	339	211	93	0
May	2	29	156	269	438	396	457	227	312	270	89	8	0
June	0	8	97	183	347	417	233	351	252	262	181	10	0
July	19	50	77	219	259	308	339	140	147	155	87	45	0
August	0	6	31	97	152	172	173	271	253	233	93	48	0
September	0	31	144	225	321	352	345	360	288	220	138	58	0
October	0	117	266	428	636	736	744	575	491	295	130	0	0
November	0	14	274	476	649	745	750	706	571	398	182	0	0
December	0	0	194	323	461	536	565	490	382	284	89	0	0
Year	0	0	31	41	152	172	173	140	147	155	33	0	0

Table 5.2.13: monthly hourly sums of E_Grid (MWh)

	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H
January	0.00	0.01	6.61	14.19	19.68	22.72	23.58	22.61	20.29	15.56	8.87	0.73	0.00
February	0.00	0.29	7.14	13.72	18.68	21.87	22.91	22.56	19.82	15.71	10.15	4.15	0.00
March	0.00	2.89	9.39	15.65	20.67	23.69	24.85	23.70	21.53	17.55	12.20	5.37	0.06
April	0.16	4.56	10.64	16.00	20.12	22.12	22.60	21.75	19.47	15.57	10.79	4.93	0.26
May	0.91	5.28	10.94	16.19	19.86	20.94	21.62	20.05	17.81	14.53	9.46	4.38	0.89
June	1.05	4.55	9.57	14.09	17.65	19.35	19.71	19.02	17.36	14.19	9.60	4.73	1.00
July	0.94	4.07	8.81	13.56	17.03	18.50	19.16	18.39	16.64	13.37	9.33	4.80	1.07
August	0.32	3.78	8.78	13.35	17.19	19.64	20.39	19.91	18.12	14.55	9.97	4.65	0.67
September	0.00	4.13	9.86	14.87	18.52	21.28	22.14	21.35	18.65	14.94	9.32	3.72	0.03
October	0.00	4.73	11.47	17.42	22.13	24.74	24.95	23.01	19.86	14.87	8.37	1.57	0.00
November	0.00	2.27	10.21	16.95	21.60	24.06	24.38	23.00	19.52	14.02	6.79	0.12	0.00
December	0.00	0.24	8.04	15.35	20.32	23.20	23.96	22.53	19.00	13.82	6.79	0.07	0.00
Year	3.39	36.82	111.46	181.34	233.45	262.10	270.23	257.89	228.08	178.67	111.65	39.21	3.98

5.3 RESULTS: In graphical form

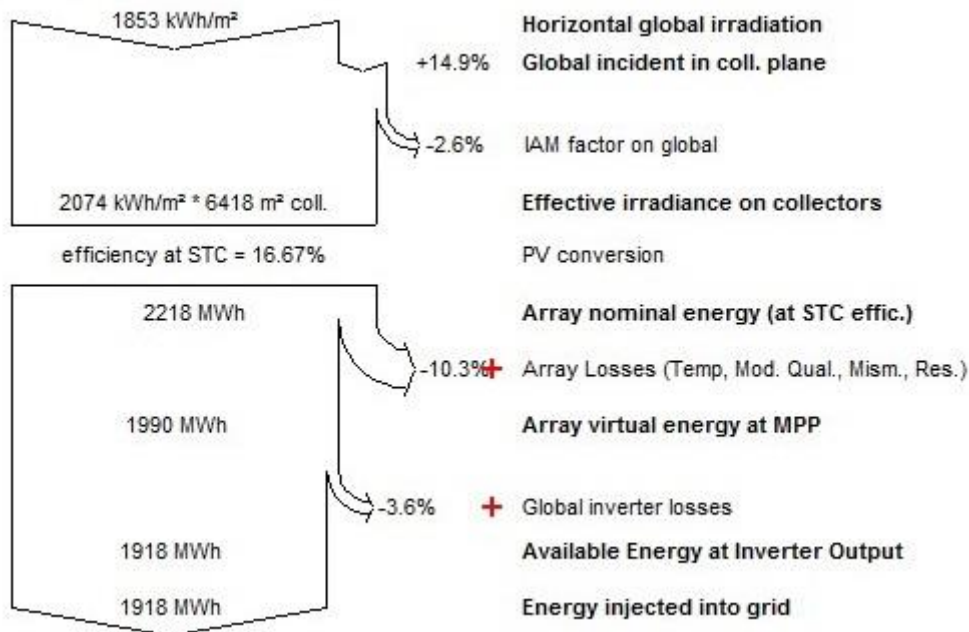


Fig. 5.3.1: Detailed system loss diagram

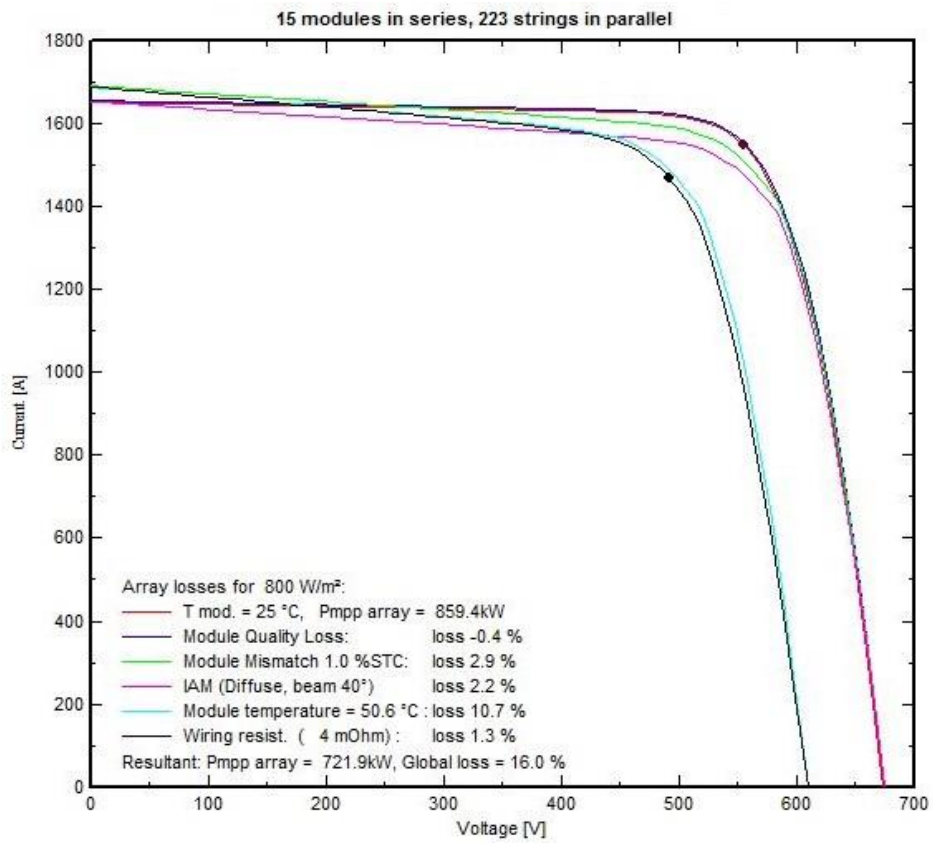


Fig.5.3.2: Array Losses curve

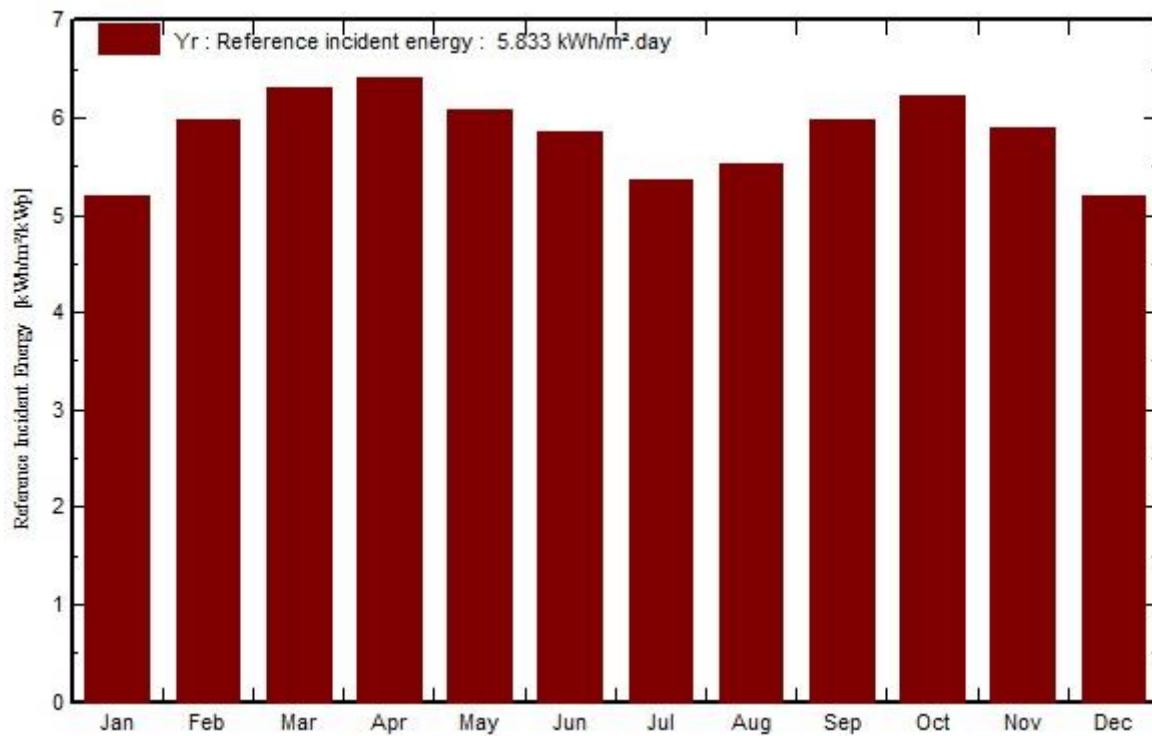


Fig.5.3.3: Reference Incident Energy in Collector Plane

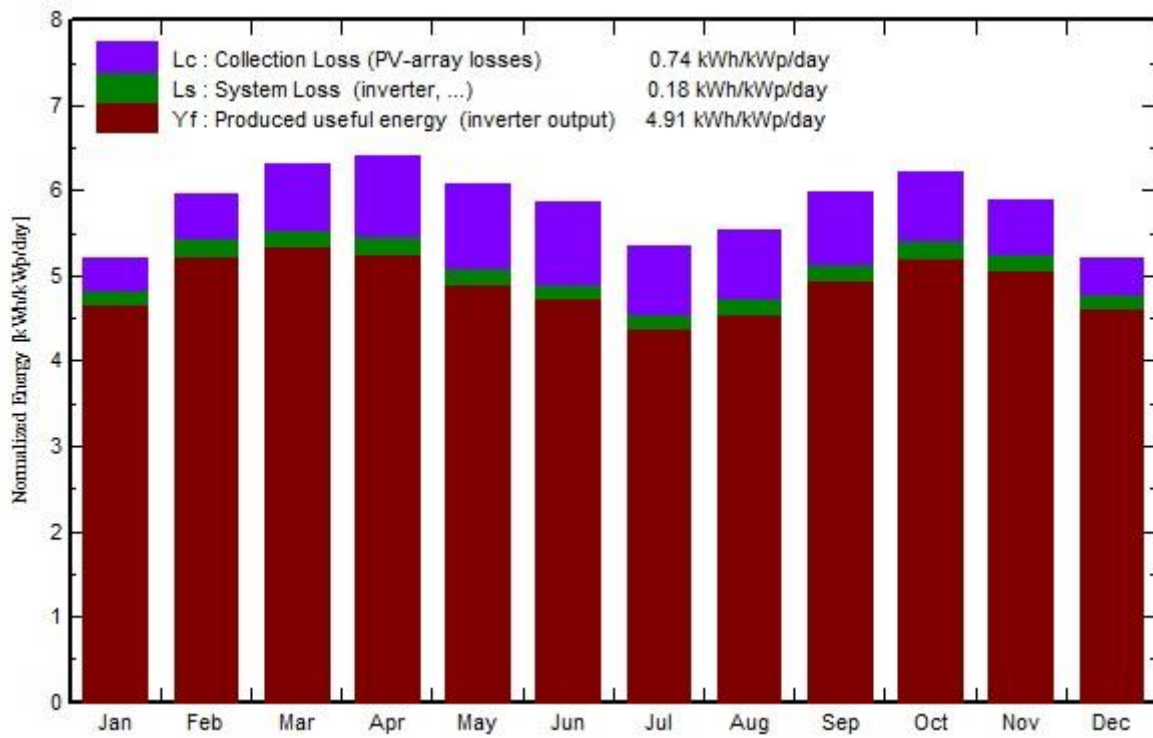


Fig.5.3.4: Normalised productions [per installed kWp]: (Nominal Power 1070 kWp)

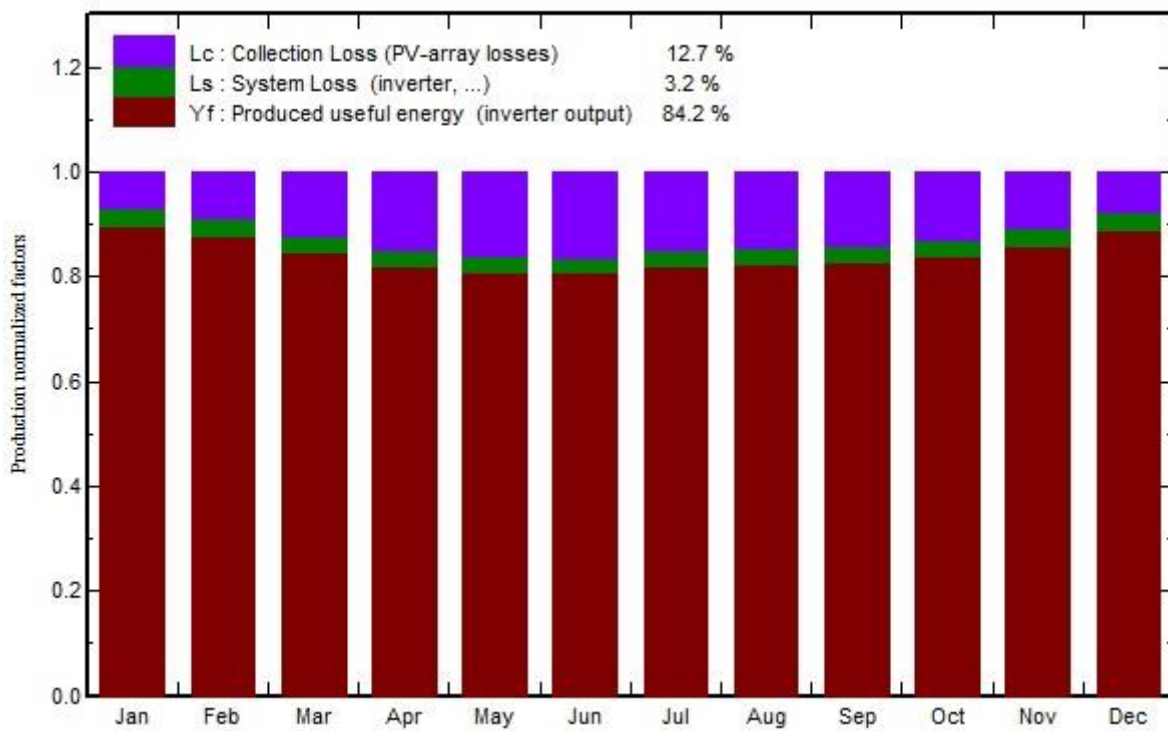


Fig. 5.3.5: Normalised productions and loss factors

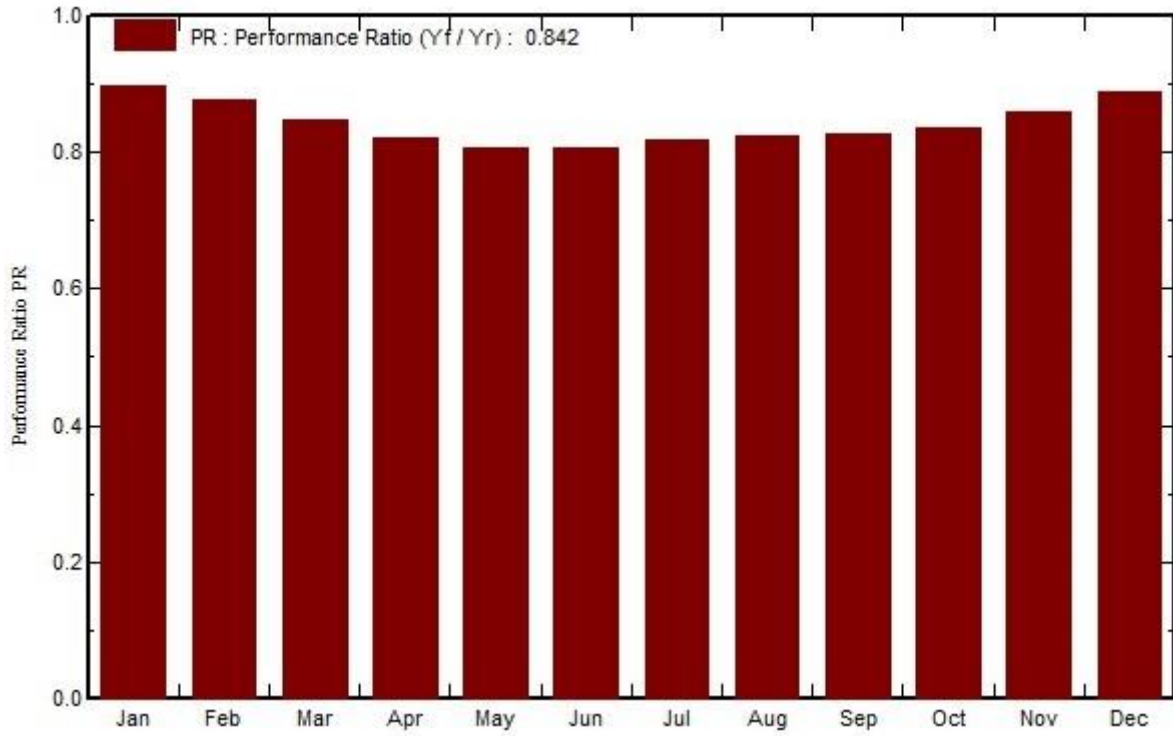


Fig. 5.3.6: Performance ratio (PR)

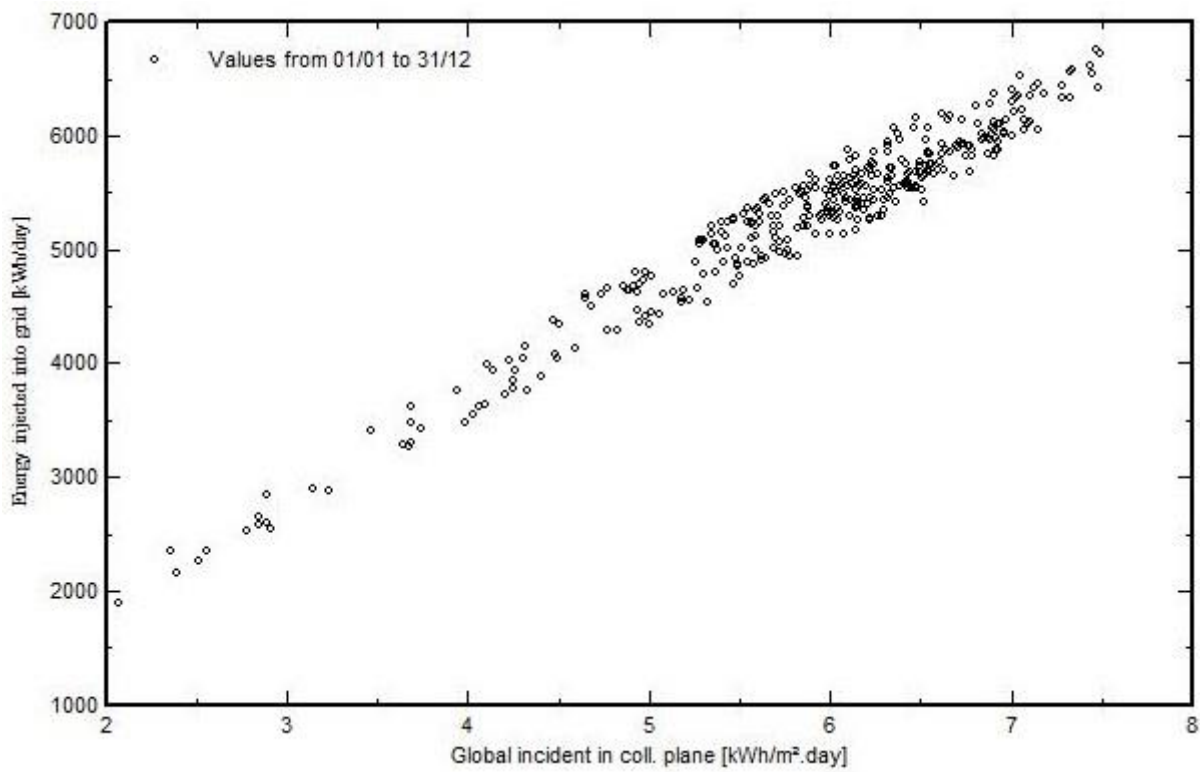


Fig. 5.3.7: Daily input output diagram

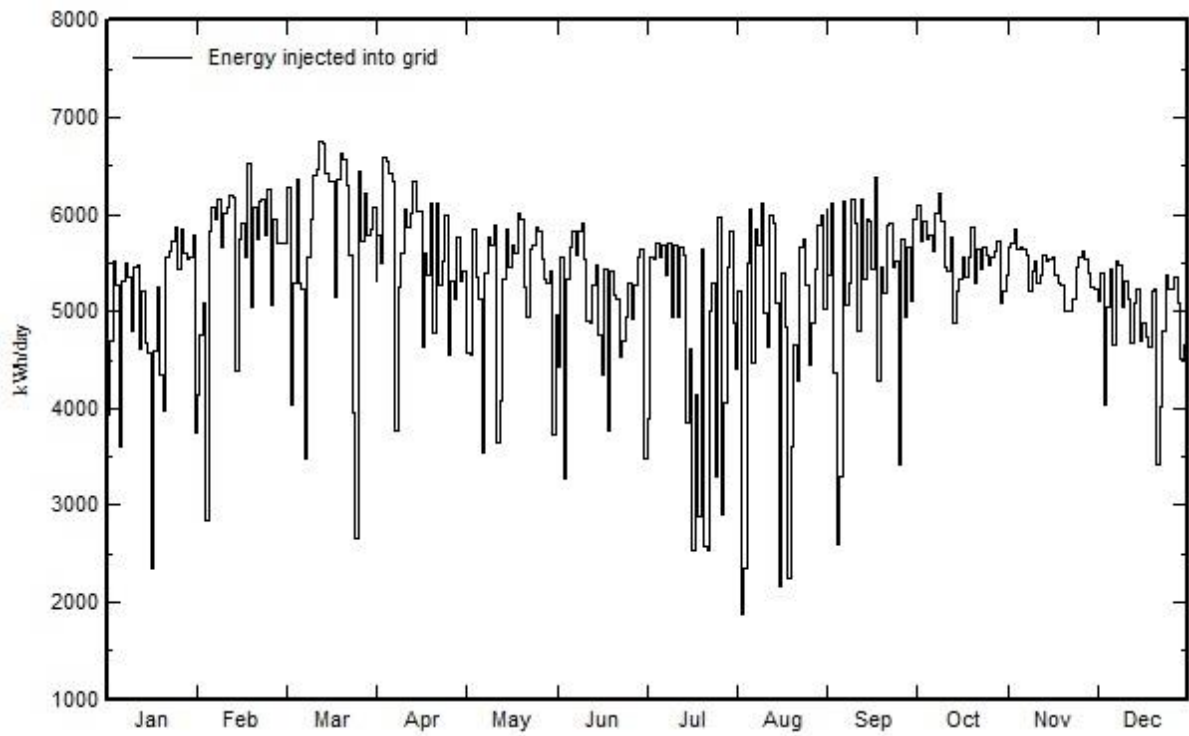


Fig.5.3.8: Daily System output energy

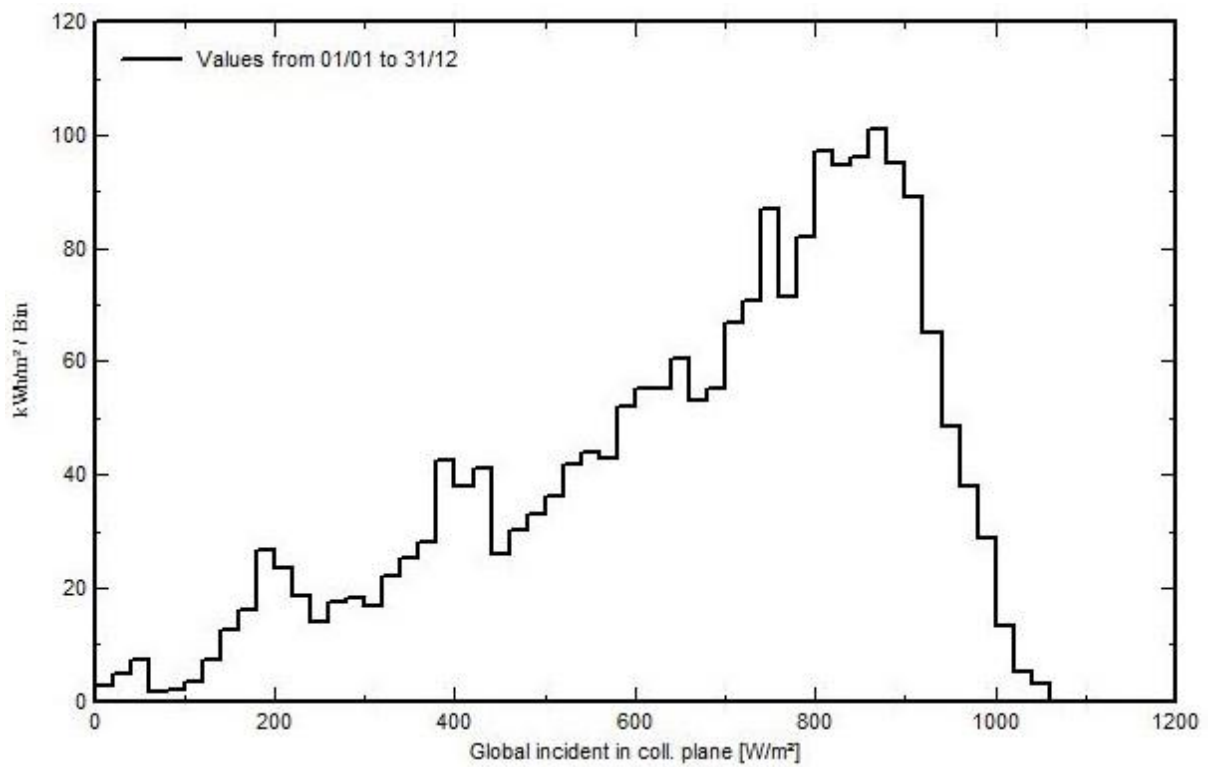


Fig. 5.3.9: Incident Irradiation Distribution

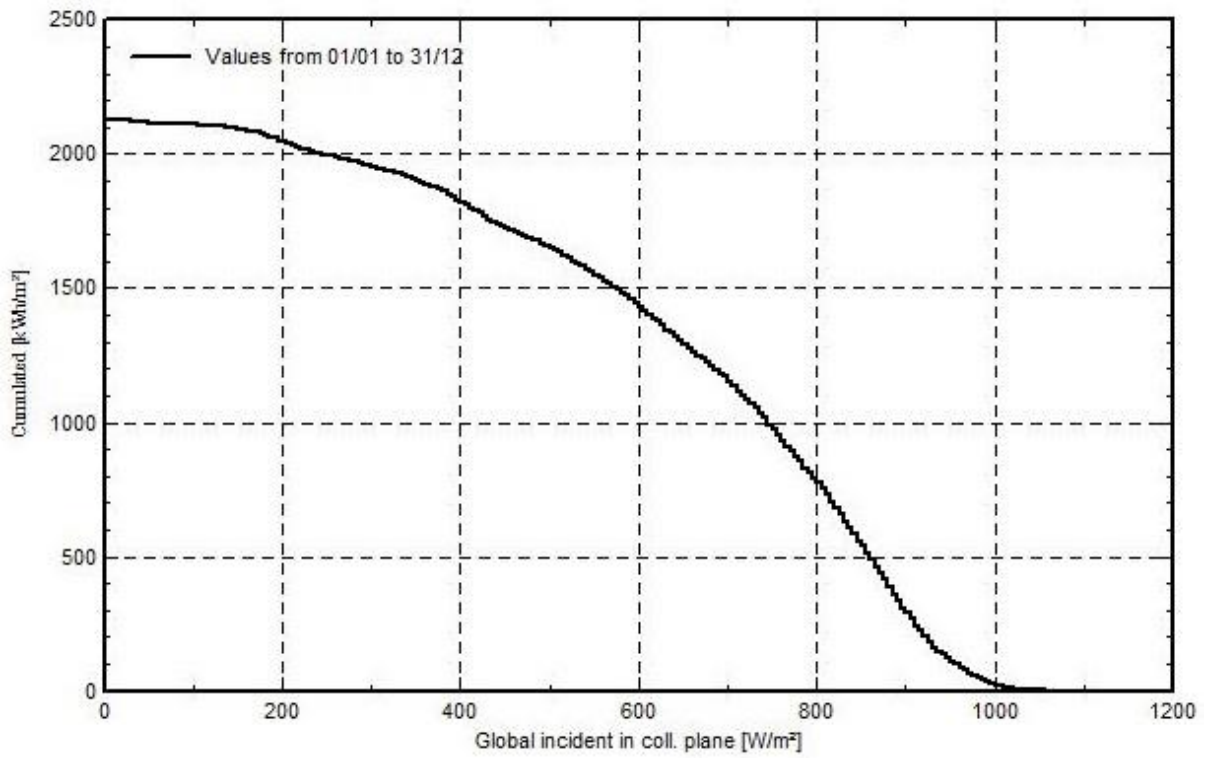


Fig. 5.3.10: Incident Irradiation Distribution cumulated

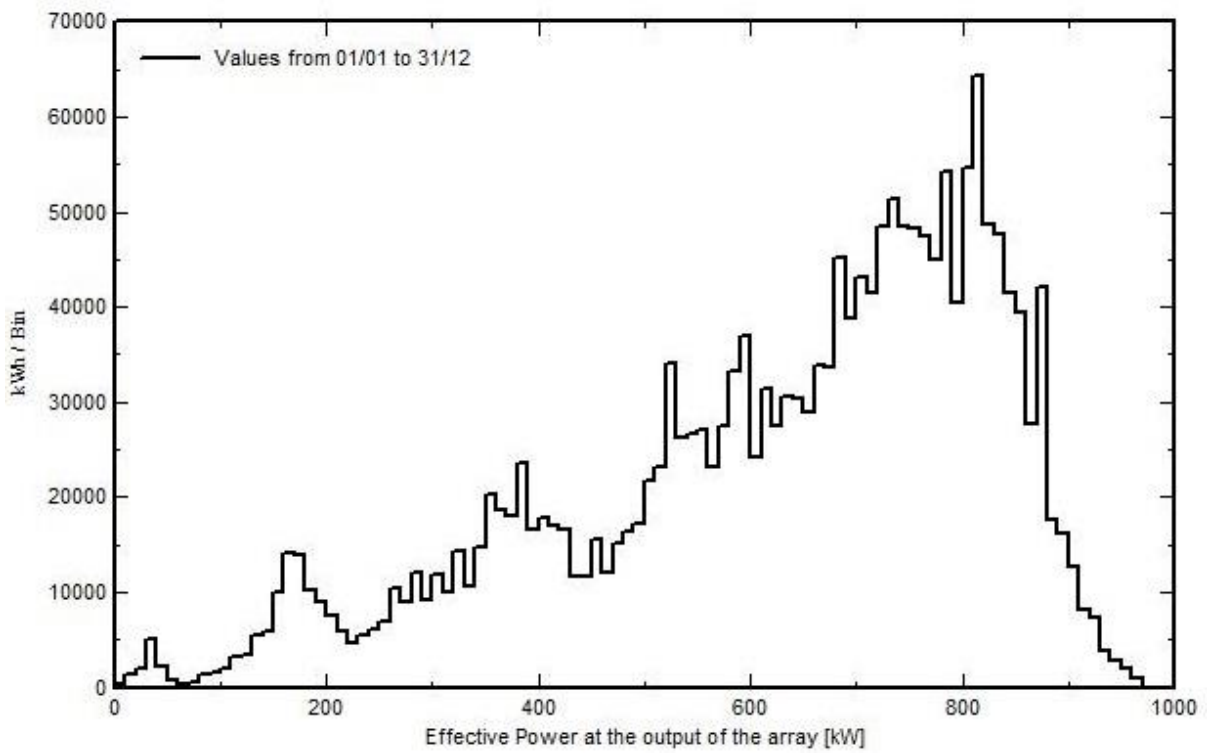


Fig. 5.3.11: Array power Distribution

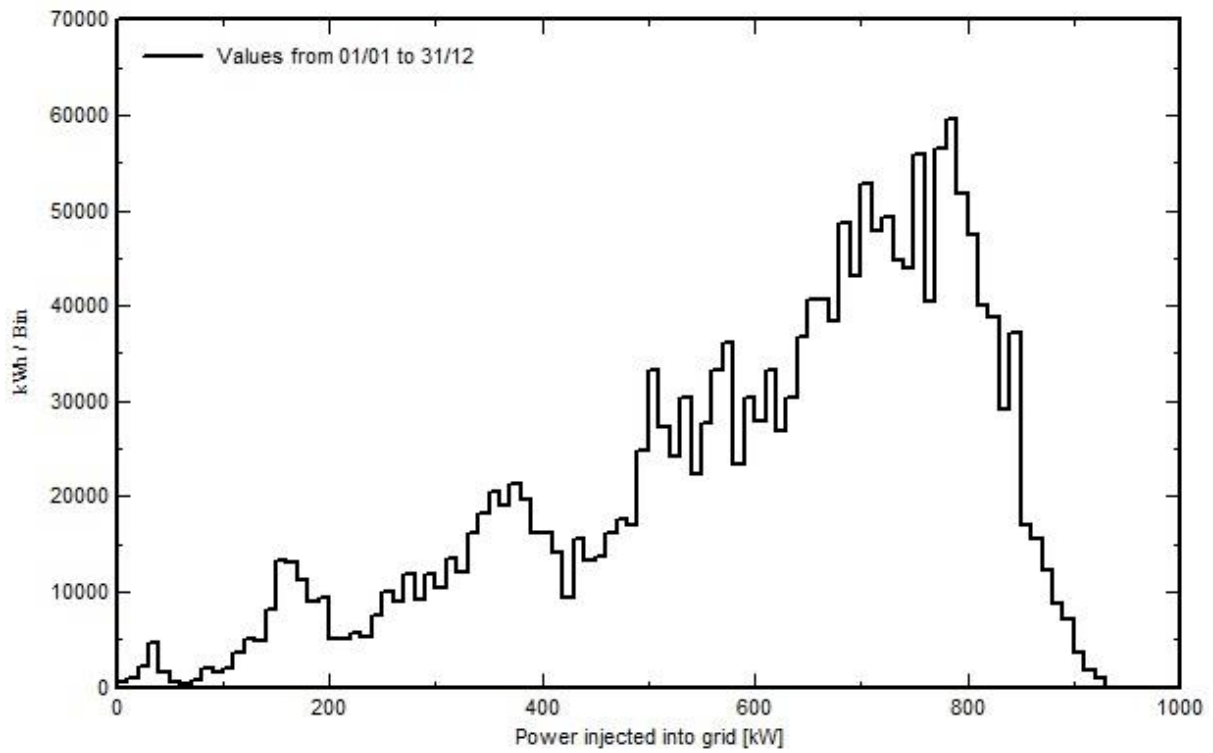


Fig. 5.3.12: System output power distribution

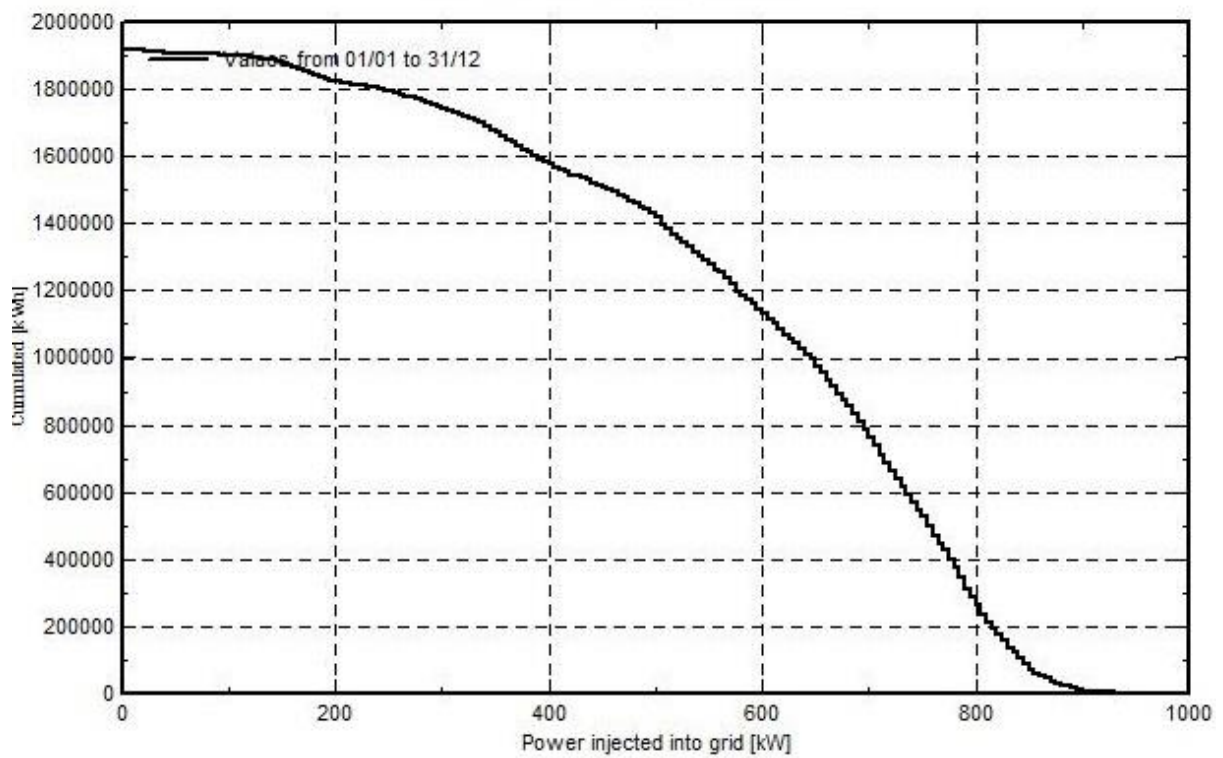


Fig. 5.3.13: System output power distribution cumulated

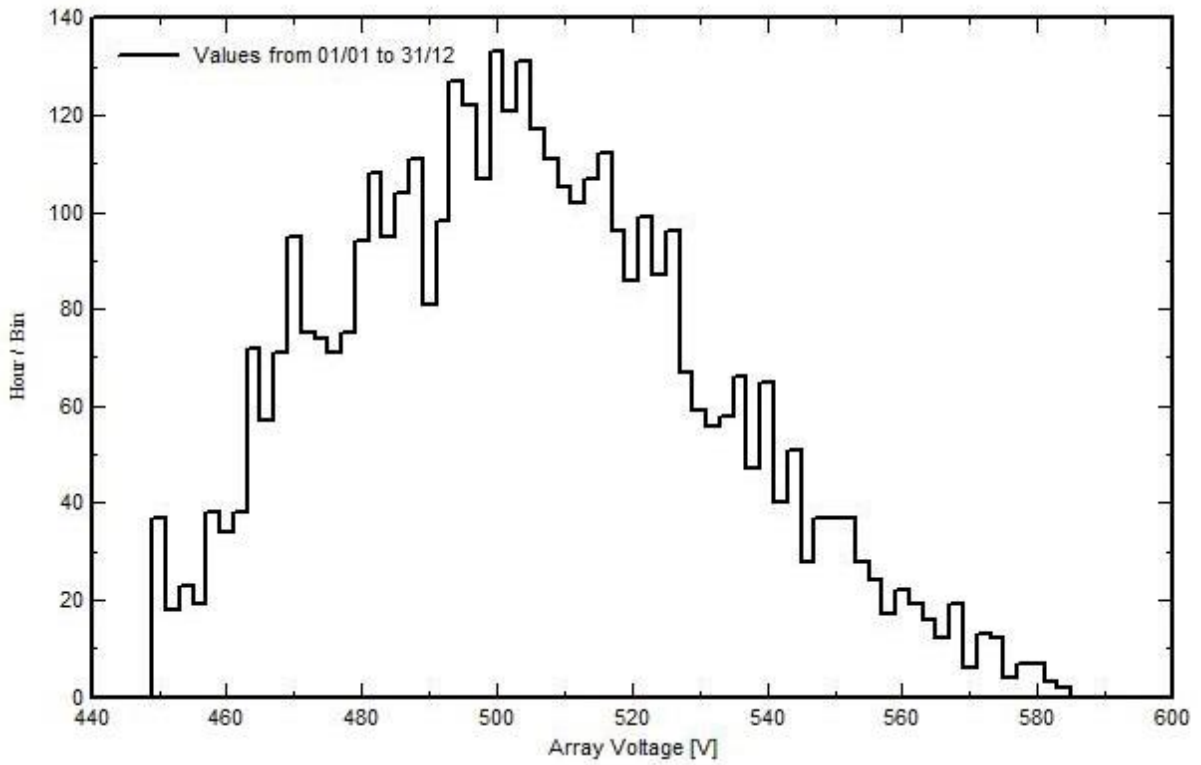


Fig. 5.3.14: Array Voltage Distribution

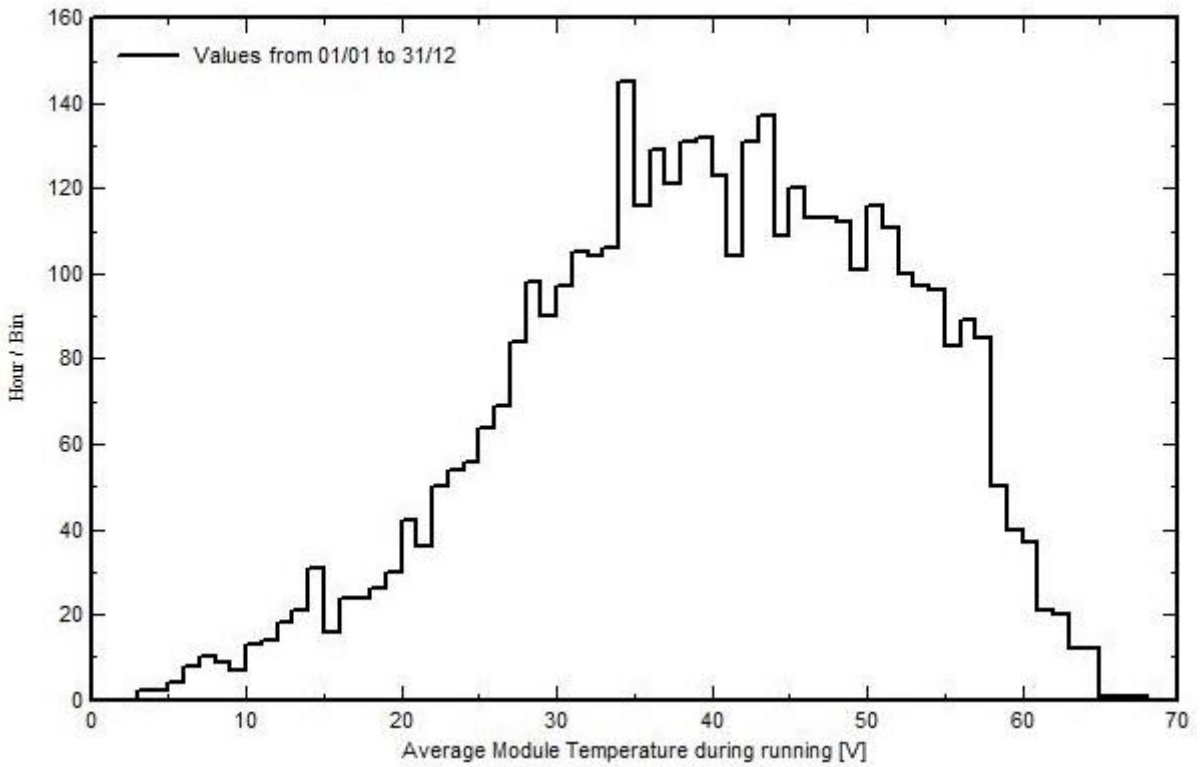


Fig. 5.3.15: Array temperature distribution during running

5.4 RESULTS: Economic

Table 5.4.1: Economic simulation results

Annuities	₹ 11709794/year
Annuity factor	17.70 %cap/year
Total yearly cost	₹ 12709794.40/year
<i>Energy produced</i>	<i>1918288 kWh/year</i>
<i>Energy cost</i>	<i>₹ 6.63 /kWh</i>
<i>Specific Investment</i>	<i>₹ 61.8 /Wp</i>

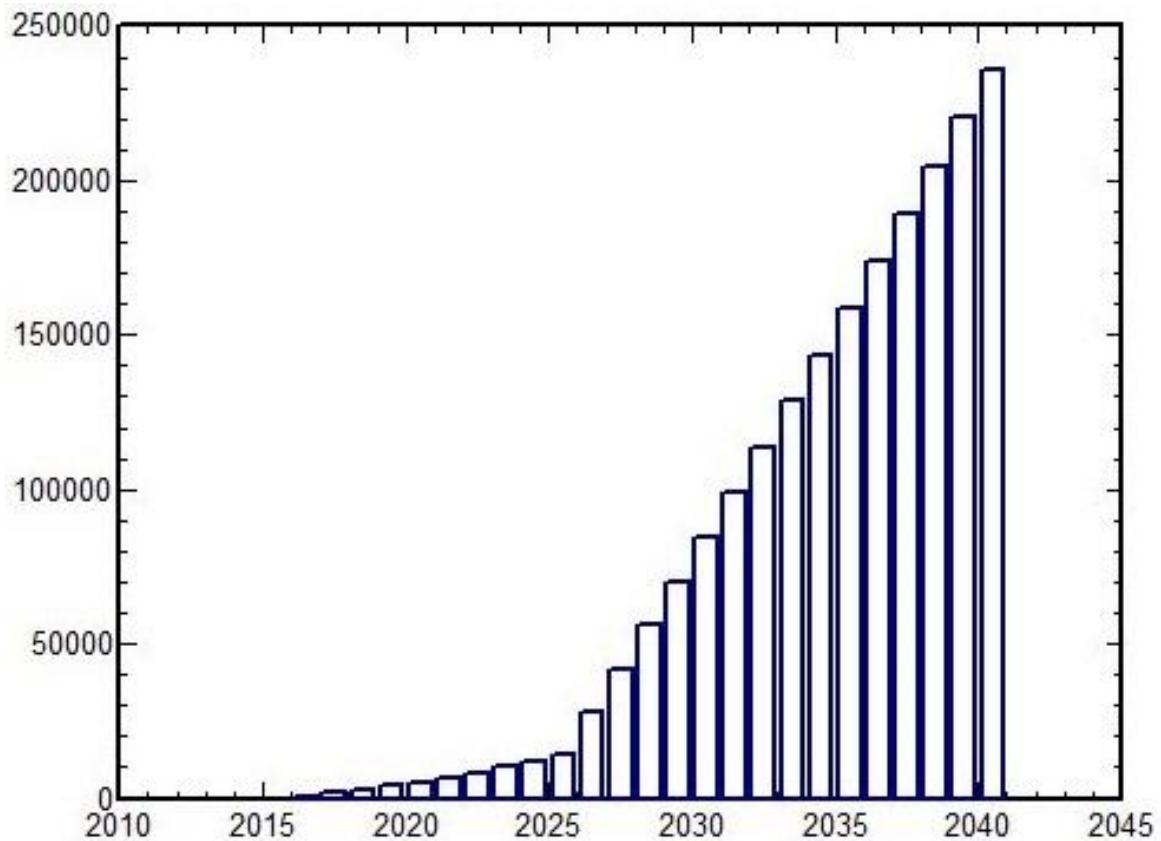


Fig. 5.4.1: Cumulated financial balance of the project for 25 years using Table 5.4.2

Table 5.4.2: Long term economic balance sheet (₹ x 1000)

Year	Loan 12.0%	Running costs	Sold Energy	Yearly Balance	Cumul. Balance
2016	11710	1000	13505	795	795
2017	11710	1000	13640	930	1725
2018	11710	1000	13775	1065	2790
2019	11710	1000	13910	1200	3990
2020	11710	1000	14045	1335	5325
2021	11710	1000	14180	1470	6795
2022	11710	1000	14315	1605	8401
2023	11710	1000	14450	1740	10141
2024	11710	1000	14585	1875	12016
2025	11710	1000	14720	2010	14027
2026	0	1000	14855	13855	27882
2027	0	1000	14990	13990	41872
2028	0	1000	15125	14125	55997
2029	0	1000	15260	14260	70258
2030	0	1000	15395	14395	84653
2031	0	1000	15530	14530	99184
2032	0	1000	15666	14666	113849
2033	0	1000	15801	14801	128650
2034	0	1000	15936	14936	143585
2035	0	1000	16071	15071	158656
2036	0	1000	16206	15206	173862
2037	0	1000	16341	15341	189202
2038	0	1000	16476	15476	204678
2039	0	1000	16611	15611	220289
2040	0	1000	16746	15746	236035

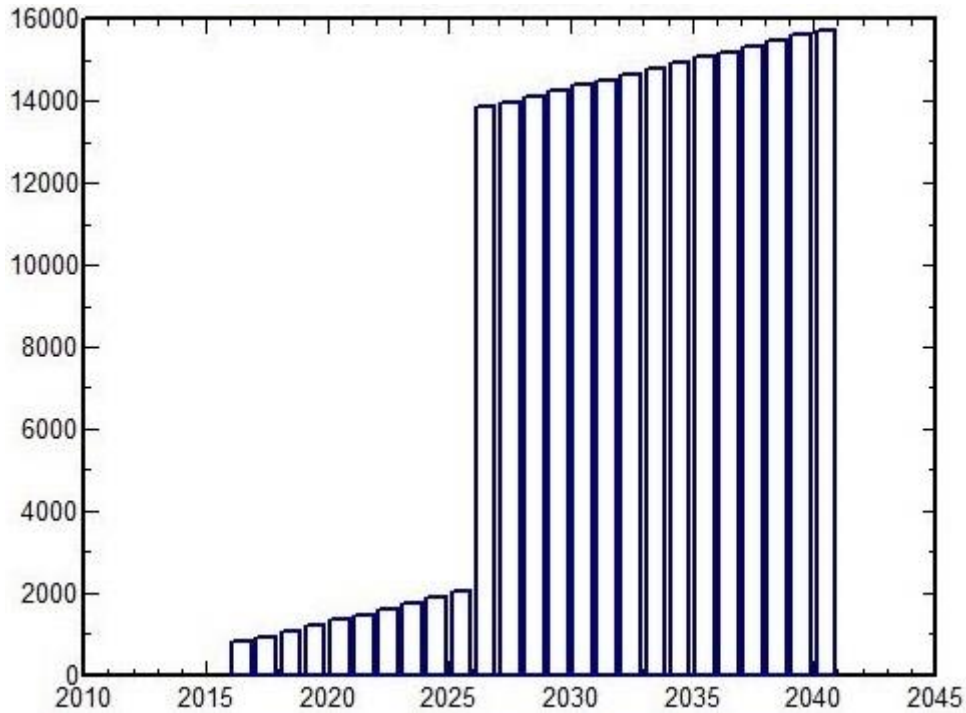


Fig. 5.4.2: Yearly financial balance of the project for 25 years using Table 5.4.2

Considering the fixed tariff of ₹ 7.04 / kWh over the lifespan (25 years) of modules & depreciation rate of 1% / year, an initial investment of ₹ 66162650 (66.2 million) can end up as a cumulative balance of ₹ 236035000 (236.035 million). Also the cost of generation is ₹ 6.63 /kWh in comparison to the tariff rate is quite low.

CARBON BALANCE

6.1 Carbon balance

Renewable energy sources help reducing carbon emissions. Conventional sources of energy release more carbon dioxide (CO₂) than their renewable. Increasing levels of CO₂ and other greenhouse gases (GHGs) in our atmosphere are leading to global warming. It would be to wrong to say that solar energy does not lead to CO₂ emissions instead it does leaves carbon footprints indirectly which are in the form of manufacturing & transportation of the modules and other paraphernalia associated with the solar plant. Carbon balance accounts for the saved CO₂ emissions saved by the solar power plant over its life cycle of 25 years.

PVsyst provides an excellent carbon balance simulation interface. The Carbon Balance tool permits to make an assessment the saving in CO₂ emissions anticipated for the PV installation. The base of this calculation are so-called Life Cycle Emissions (LCE), which characterises the emissions of CO₂ related to a given component or energy amount. These values take account of the total life cycle of a component or energy amount, including production, operation, maintenance, disposal, etc.

$$\text{Carbon balance} = E_{\text{Grid}} \times \text{system lifetime} \times \text{LCE Grid} - \text{LCE System}$$

Where LCE stands for Life Cycle Emissions

Produced emissions

$$\text{Total} = 2041.44 \text{ t.CO}_2$$

Table 6.1.1: System lifecycle emission details

Item	Modules	Supports Etc.
LCE	1713 Kg CO ₂ / kWp	6.24 Kg CO ₂ /Kg
Quantity	1070 kWp	33450 Kg
Subtotal [Kg CO₂]	1832610	208832

Replaced emissions

$$\text{Total} = 44887.94 \text{ t.CO}_2$$

$$\text{System production} = 1918.29 \text{ MWh / year}$$

Lifetime = 25 years

Annual degradation = 1 %

Grid lifecycle emissions = 936 g CO₂/ kWh

CO₂ emission balance = 37851.1 t.CO₂

The private player/invertor can also earn Renewable Energy Certificates (RECs) for the electricity generated by the SPV power plant which can be traded/sold in the market to encash extra monetary benefits from it. (*1REC = 1MWh*)

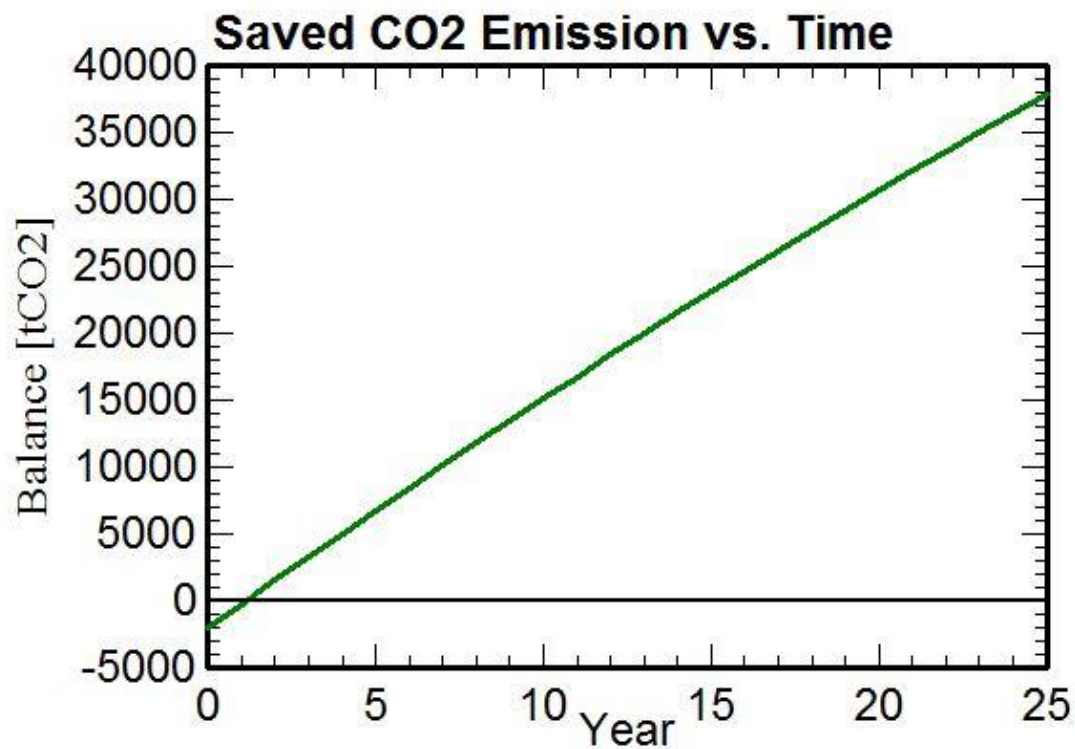


Fig. 6.1.1: Saved Carbon Emissions Yearly

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

The thesis presents an extensive study of the feasibility of 1070 kWp grid connected SPV at Lubanianwali, Sri Muktsar Sahib (Punjab), INDIA. The findings of the study are very optimistic. The study has been carried out using Canadian Solar Inc. CS6X-320P modules due to their high efficiency. Meteorological data from NASA-SSE has been analysed for the site. The results show overwhelming response in the amount of electricity which can be generated at the site. The project feasibility analysis has been carried out using the PVsyst 6.39 software for calculating the electric energy production, economic and greenhouse gases emission analysis.

The results show that 1918288 kWh of renewable energy can be produced annually with maximum production of 177553 kWh in the month of March. The annual average performance ratio is 84.2%, peaking in the month of January to 89.7%. The normalised value of energy production is 4.91 kWh/kWp/day.

The net investment on the project is ₹ 66162950 and the specific investment comes out to be ₹ 61.8/Wp. The cost of energy production per unit (kWh) is ₹ 6.63 which can ensure a good profit for the investor against the sale price of ₹ 7.04 (fixed tariff) to the utility (PSPCL). The investor can earn a cumulative balance of ₹ 236.035 million over the life span of 25 years of the project.

In addition to the economic viability, the project is evaluated for carbon emission analysis which shows that the SPV power plant can reduce the CO₂ emissions to the environment to the tune of 37851.1 tonne over entire life span of the project. Overall, the investigation confirms the SPV power plant feasibility at the proposed site with good profitability.

7.2 Future Scope

The future scope of present research work is identified as:

- Study and simulate the project for seasonal tilt orientation and find the variation in energy output and change in cost of generation.

- Also, the project can be studied and implemented using the sun tracking systems and compute the change in energy production, add the additional costs of the sun tracking systems & finally calculate the new cost of generation.
- Economic parameters like simple payback period and life cycle costing can be evaluated

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