

# Performance Evaluation of Grid-Connected Solar Photovoltaic Plant using PVSYST Software

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**Abstract**— Due to increase in the price of fossil fuel and decrease in the coal resources, renewable energy has become the new future of energy generation of India. The time of coal based power generation has come to its end, thus its imperative to look for new and innovative ways to generate energy. Renewable energy is slowly but surely making its way into every household. The focus of our project is Out of all the available renewable energy sources, Solar Energy is the most abundant, and is basically an infinite source of energy. This energy has to be put to proper use in order for humanity to reach new levels in innovation and technology. There is a huge scope solar energy in India in states like Karnataka, Telengana, Rajasthan, Andhra Pradesh, Tamil nadu, Gujarat etc. There are about 23,789 sq kilometer area of land in non productive use. Rajasthan is a desert and it receives ample amount of solar energy throughout the year and very little rain fall. Therefore it is an ideal place for the construction of a solar power plant. PVsyst is a software used to design solar panels or even a solar power plant.

**Keywords**— PVsyst (Photovoltaic System), solar plant, renewable energy

## I. INTRODUCTION

Due to increase in the price of fossil fuel and decrease in the coal resources, renewable energy has become the new future of energy generation of India. The time of coal based power generation has come to its end, thus its imperative to look for new and innovative ways to generate energy. Renewable energy is slowly but surely making its way into every household. The focus of our project is Out of all the available renewable energy sources, Solar Energy is the most abundant, and is basically an infinite source of energy. This energy has to be put to proper use in order for humanity to reach new levels in innovation and technology.

There is a huge scope solar energy in India in states like Karnataka, Telengana, Rajasthan, Andhra Pradesh, Tamil nadu, Gujarat etc. There are about 23,789 sq kilometer area of land in non productive use. Rajasthan is a desert and it receives ample amount of solar energy throughout the year and very little rain fall. Therefore it is an ideal place for the construction of a solar power plant. PVsyst is a software used to design solar panels or even a solar power plant.

## II.METHODOLOGY

There are various components in PVsyst software. The specifications for these components are researched and entered in the software. The software collects all the data and stimulation is run on the software and result is produced. The various components whose specifications are researched and entered are the geographical site and its weather conditions throughout the year, the orientation of solar panel, the various components of the system, the details of losses, the horizon and the stimulation is generated

### A. Meteo data base

So since we have selected the site we have we have to enter the geographical data of the particular location. There is feature called interactive map where we can select the geographical location of the site. The latitude of the site is 28.2900 north and the longitude 74.2343 east. Altitude 249 above sea level. Other data like horizontal global irradiation, horizontal diffusive irradiation, temperature, wind velocity, linke turbidity, relative humidity on a per month basis throughout the year could be found from the Meteonorm. Thefigure 1 below will give u the data

	Horizontal global irradiation kWh/m <sup>2</sup> .mth	Horizontal diffuse irradiation kWh/m <sup>2</sup> .mth	Temperature °C	Wind Velocity m/s	Linke Turbidity [-]	Relative Humidity %
January	118.0	36.1	15.3	0.89	3.656	48.9
February	137.3	36.3	19.5	1.20	3.483	44.7
March	178.3	54.9	25.7	1.39	3.968	31.5
April	194.6	71.7	30.6	1.60	5.562	26.7
May	204.8	94.8	35.4	2.49	7.000	29.6
June	191.0	98.0	34.7	2.60	7.000	43.1
July	172.4	94.6	33.3	2.40	7.000	56.3
August	170.0	93.3	32.1	1.99	5.965	60.0
September	165.8	66.1	31.1	1.40	4.675	53.7
October	150.8	55.3	28.6	0.90	4.272	37.5
November	124.0	34.8	22.2	0.71	3.600	39.6
December	113.2	31.2	17.3	0.70	3.600	48.3
Year	1920.2	767.1	27.1	1.5	4.982	43.3

Fig 1. Meteonorm data of Asasar

### B. Orientation

The orientation of the solar panel decides the tilt angle and the azimuth angle. There are various field types available. For this project, seasonal field type is used. Due to the sun path and geographical we kept a summer tilt of 16 degree and winter tilt of 47 degree and because there is no elevation the azimuth is 0 degree. This is kept to ensure minimum amount of loss during the summer and winter months. In Rajasthan winter falls from October to March so tilt will be kept 47 degree and from April to September it is kept 16 degrees.

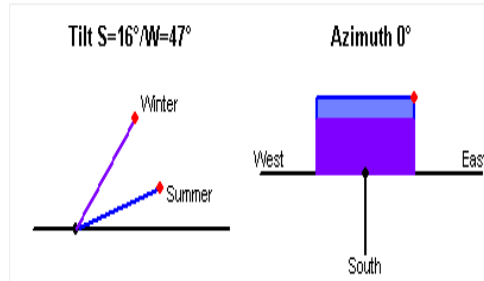


Fig 2. Tilt and Azimuth angle

### C. Configuration of the system

The simplified schematic diagram of the system is given below

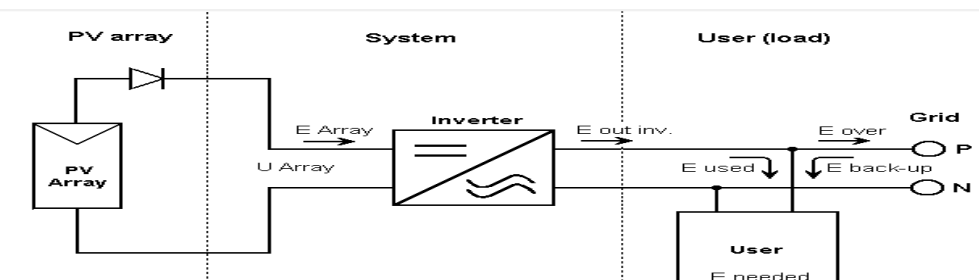


Fig 3. Schematic diagram of the system

The pv array is connected to an pv inverter which is then connected to a battery where the energy is stored. As shown in figure 3

#### 1) PV array

**Solar cell:-** A solar cell is a p-n junction diode made of silicon. A current is produced when electrons are moved in the diode due to hitting of the sun's rays. As shown in figure 4.

A number of solar cells connected in series forms a Solar Module. Then a number of solar modules connected in series are called a Solar String. Then a number of solar strings connected in series is called a solar array. As shown in figure 5.

The no. of sub-arrays used in this project is 1

The no. of modules in series is 16

The no. of strings is 125

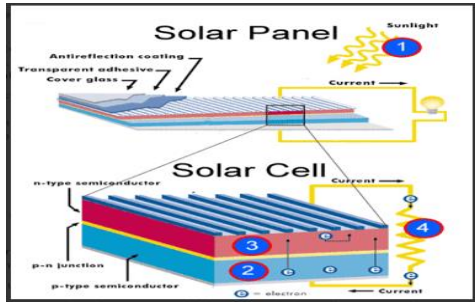


Fig 4. Solar cell

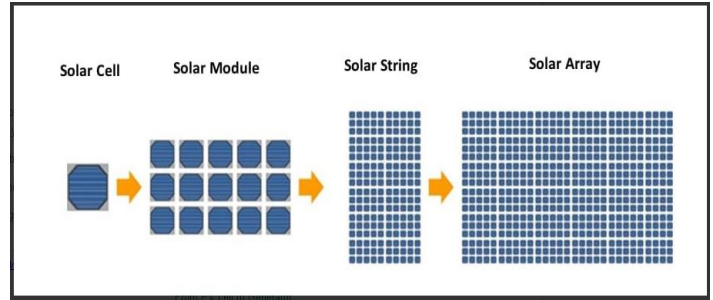


Fig 5. Solar Panel

## 2) PV module

PV module that is being used in this project is 250 wp 26V Si-mono 250 wp 60 cells Bifacial since 2015. The details of the PV module used are given below.

Size	Cell
Length=1640mm	In series= 60
Width= 992mm	In parallel=1
Thickness = 50mm	Cell area=237cm <sup>2</sup>
Weight = 19.8kg	Total no. of cell=60
Module area=1.67m <sup>2</sup>	Cell area=1.422m <sup>2</sup>

### Module technology and specifications

Frame: Aluminum

Structure: 3.2 mm tempered

Connection: MC-4

Generic module for DEMO

### Model summery

R shunt=300Ω	Gamma=0.913
Rsh (G=0) =1200Ω	IoRef=0.02nA
R series model 0.29Ω	muVoc= -140mV/°C
R series max. = 0.45Ω	muPMax fixed = -0.45/°C
R series Apparent = 0.45Ω	

### Internal model result tool

Operating condition GOper =1000W/m<sup>2</sup> TOper = 25°C

Max power point Pmpp=249.9W Temper. Coeff =-44%/°C

Current Impp=8.15A Vmpp=30.7V

Short-circuit Current Isc 8.63 A Open circuit Voc=37.4V

Efficiencyv/cells area 17.57% Model area=15.36%

a) *Manufacturer Specifications - Obtained from Datasheets:* These parameters are the main electrical module characteristics, available on any manufacturer data sheets. They are usually given for STC, but the program accepts measurements performed under other conditions to establish the model from on-site measurements in outdoor conditions. These parameters therefore include:

- Gref and Tref: the reference irradiation and module temperature conditions during reference measurements (usually standard test condition STC)
- Isc and Voc: module short circuit current and open circuit voltage at these given conditions.
- Impp and Vmpp: any operating point *in the region of* the maximum power point at these given conditions.
- muIsc: temperature coefficient for Isc. This has only weak influence on the module behavior. When not known, it can be taken as about 0.05%/°C

### Manufacturer specifications or other measurement

Reference condition  $G_{ref}=1000W/m^2$

Short-circuit current  $I_{sc}=8.630A$

Temperature Coefficient  $\mu_{sc}=4.3 mA/^{\circ}C$

Open circuit voltage  $V_{oc}=37.40V$

$T_{ref} = 25^{\circ}C$

$V_{mpp}=30.70V$

These are the 2 main parameters of the one-diode model. PVsyst always proposes default values which may be recovered by clicking the "Default" checkboxes.

**Rshunt:** It is the inverse of the slope  $-dV/dI$  of the I/V curve around the  $I_{sc}$  value. The default value proposed by PVsyst corresponds to a given fraction of the slope  $(I_{sc}-I_{mpp}) / V_{mpp}$ . With modern crystalline modules the Rshunt is high (i.e. the curve is very flat) and the associated loss is therefore low, so that an accurate determination is not crucial

**Rseries** is the internal series resistance of the one-diode model. It is one of the parameters of the model at STC, not directly measurable using the I/V curve. Its determination is crucial, and has consequences on the low-light performances

### Model summery

R shunt=300 $\Omega$	Gamma=0.913
Rsh ( $G=0$ ) =1200 $\Omega$	$I_{oRef}=0.02nA$
R series model 0.29 $\Omega$	$\mu V_{oc}= -140mV/^{\circ}C$
R series max. = 0.45 $\Omega$	$\mu P_{Max}$ fixed = $-0.45/^{\circ}C$
R series Apparent = 0.45 $\Omega$	

b) **Bifaciality factor:** In PVsyst, such "Bifacial modules" will be characterized by their "Bifaciality Factor", i.e. the ratio of the nominal efficiency at the rear side, with respect to the nominal efficiency of the front side. Remember that the nominal efficiency is simply the nominal Power (under STC) expressed in [kWp], divided by the area of the PV module [ $m^2$ ].

Bi-Facial module

Bifaciality factor = 0.800

### c) Model parameters

Rshunt : 300 $\Omega$

Rseries 0.289 $\Omega$

Series resistance maximum for the model:0.310 $\Omega$

Series residence  $dv/dI$ :0.54 $\Omega$

Diode saturation current  $I_{oRef}$  0.024nA

Diode quality factor Gamma 0.91-0.001/K

Voltage temperature coefficient  $\mu V_{oc}$ -140.3mV/ $^{\circ}C$

The I/V characteristics has to pass through the three gi  
Mpp

Diode saturation current and voltage temperature coeffi  
determined by this requirement

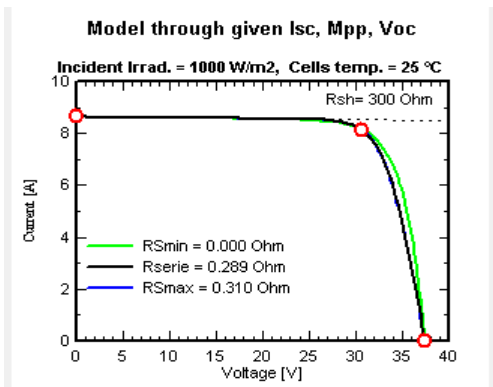


Fig 6. Graph Current (A) vs Voltage (V)

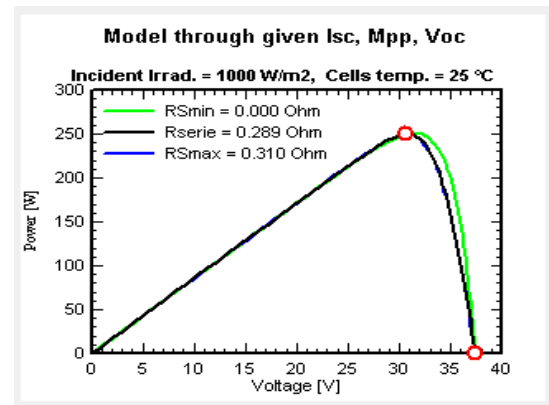


Fig 7. Graph Power (W) vs Voltage (V)

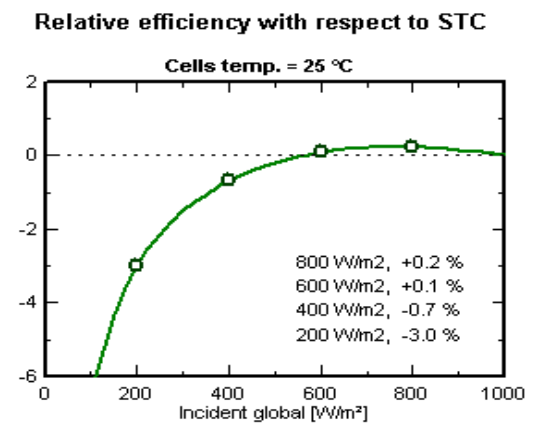


Fig 8. Graph Relative efficiency (%) vs Incident global (W/m²)

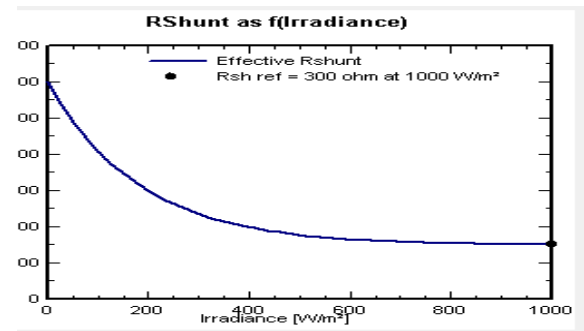


Fig 9. Graph Rshunt as a function of Irradiance

### R Shunt exponential

Rshunt at  $g_{inc} = 0$  : 1200Ω

Exponential parameter 5.5

### Temperature coefficient

$\mu P_{Max}$  and  $\mu V_{oc}$  temperature coefficient settings  $\mu P_{Max}$  and  $\mu V_{oc}$  Temperature coefficient are output parameters of the standard one-diode model, which are dependent on Gamma choice

$P_{mpp}$  temperature coefficient ( at STC ) : -0.450%

=> Gamma temperature coefficient: -0.066%

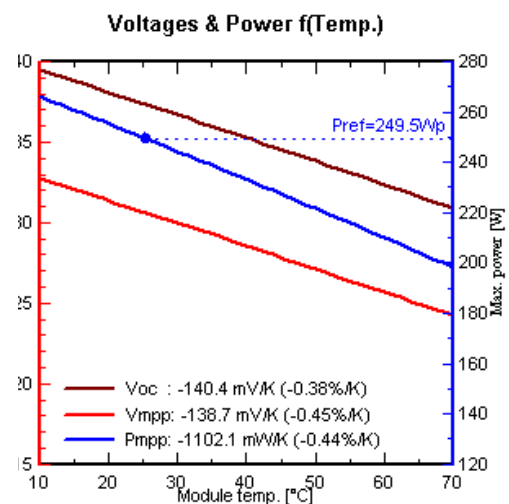


Fig 10. Graph voltage & Power vs temperature

d) Additional data

Customized IMA

Incidence angle: The incidence effect (the designated term is IAM, for "Incidence Angle Modifier") corresponds to the decrease of the irradiance really reaching the PV cells' surface, with respect to irradiance under normal incidence. This decrease is mainly due to reflex ions on the glass cover, which increases with the incidence angle.

The front glass used: Fresnel normal glass

TABLE 1 INCEDENT ANGLE MODIFIER

	Incident an	IAM
1	0.0	1.000
2	30.0	0.998
3	50.0	0.981
4	60.0	0.948
5	70.0	0.862
6	75.0	0.776
7	80.0	0.636
8	85.0	0.403
9	90.0	0.000

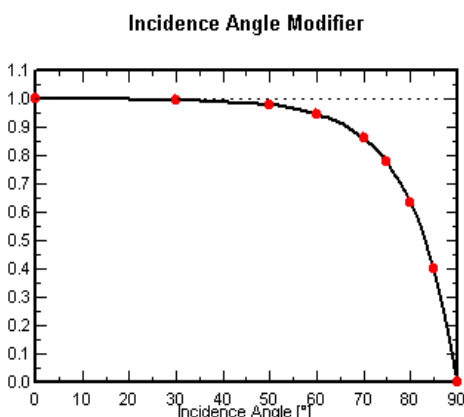


Fig 11. Graph Incidence Angle Modifier

e) Secondary Parameters

- *MuIsc*: (often named Alpha) is specified on the main page of the parameters, and used as such in the model. For crystalline modules, its value lies usually between 0.04 and 0.08 %/°C

Specified muVsc: -127mV/°C

- *Absorption Coefficient for temperature*:

Absorptivity coefficient (alpha) : 0.9

This is the Irradiance global absorption coefficient involved in the thermal balance for determination of the array temperature

- *Reverse characteristics*:

Single cell reverse characteristics

Quadratic factor BRev: 3.2 mA/V<sup>2</sup>

NB. This reverse parameter is only used in the framework of the array behavior special tools (partial shading on modules).

It value is not essential and can be taken as the proposed default.

Number of by-pass diodes: 3/module

Diode direct voltage: -0.7V

Diode maximum current: 0A

- f) *PV Module model: graphs*: In the PV module definition dialog, the page "Graphs" shows the general behavior of the model. You can display the following sets of curves:

- Current vs Voltage (often named "I/V curves")
- Power vs voltage (often names "P/V curves"),
- Efficiencies as a function of the irradiance.
- Efficiencies as a function of the temperature.

These plots show sets of parametric curves, i.e. for different Irradiances, Temperatures, Series resistance or Shunt resistance

Graph parameter: Incident radiance

red: 1000W/m<sup>2</sup> green:800 W/m<sup>2</sup> purple: 600 W/m<sup>2</sup> blue: 400 W/m<sup>2</sup> grey  
: 200W/m<sup>2</sup>

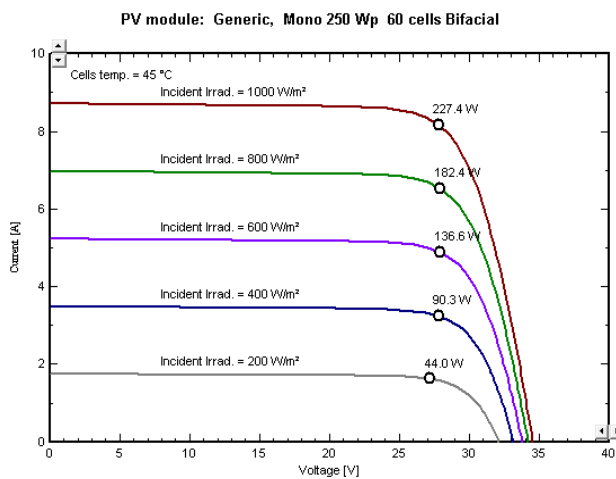


Fig 12. Graph Current vs Voltage

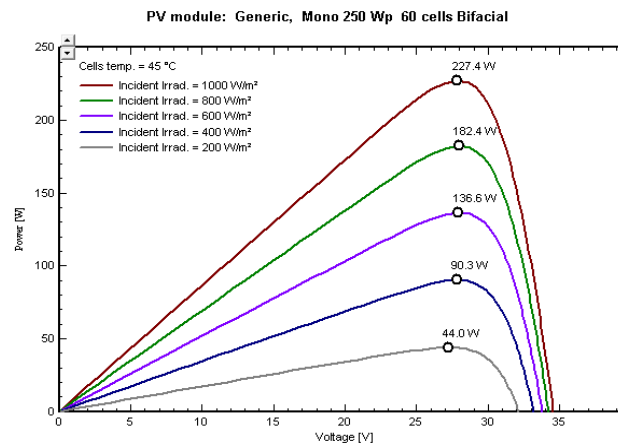


Fig 13. Graph power vs Voltage

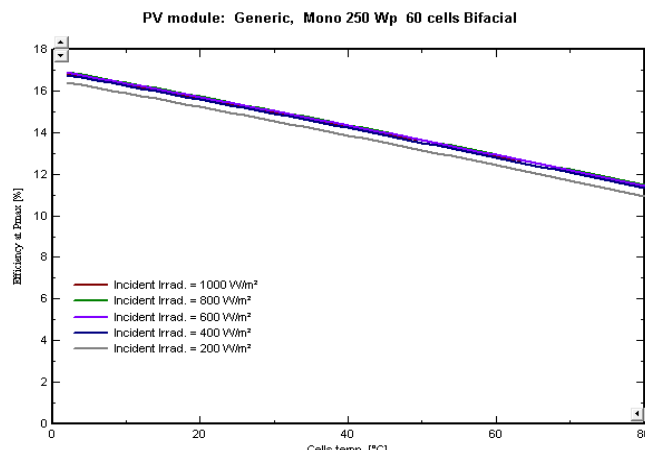


Fig 14. Graph Efficiency vs temperature

Graph parameter: temperature

red: 10°C green: 25°C purple: 40°C blue: 55°C grey :  
70°C

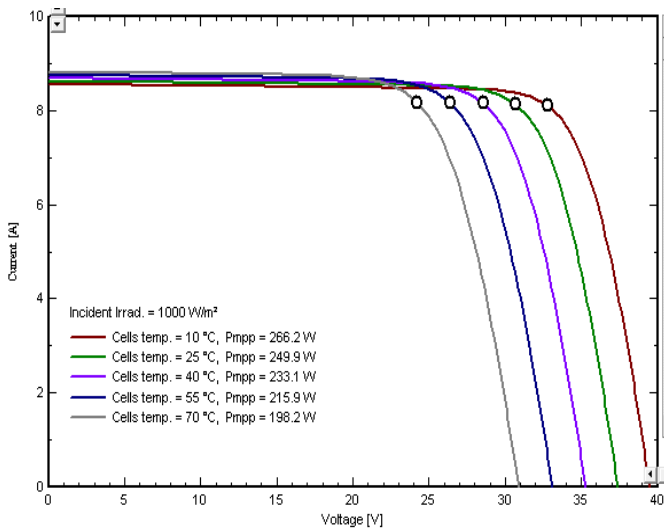


Fig 15. Graph Current vs Voltage

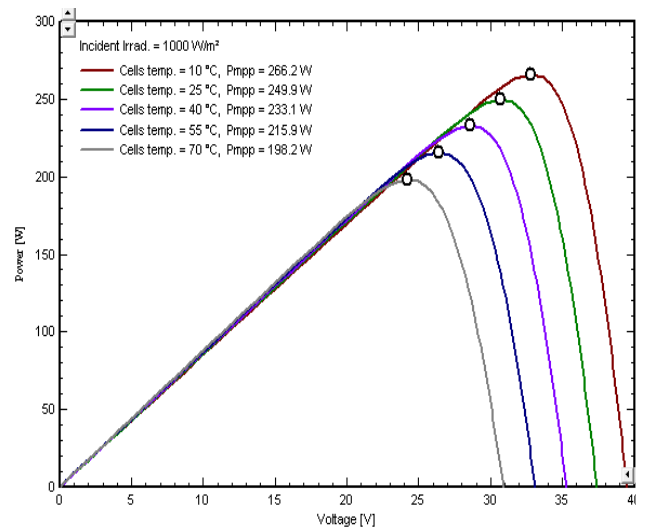


Fig 16. Graph power vs Voltage

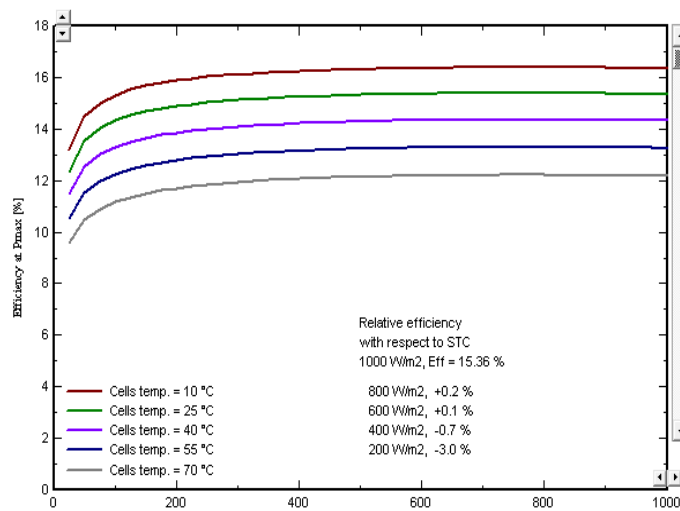


Fig 17. Graph Efficiency vs temperature



Graph parameter: Series resistance

red: 200Ω green: 400Ω purple:600Ω blue: 800Ω  
grey : 1000Ω

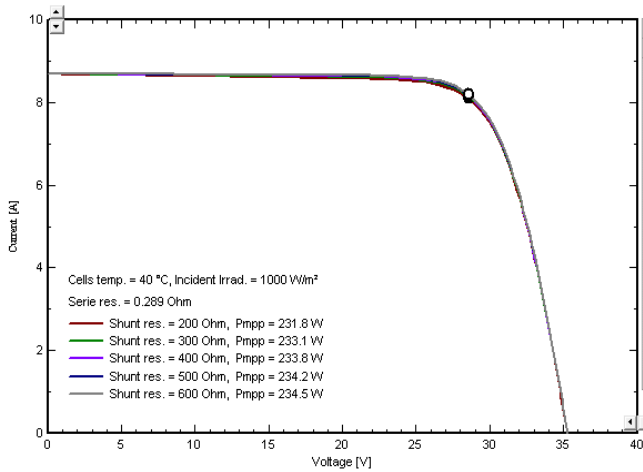


Fig 18. Graph Current vs Voltage

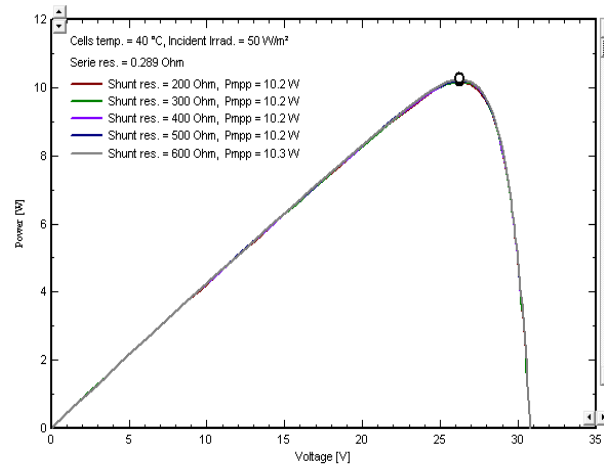


Fig 19. Graph power vs Voltage

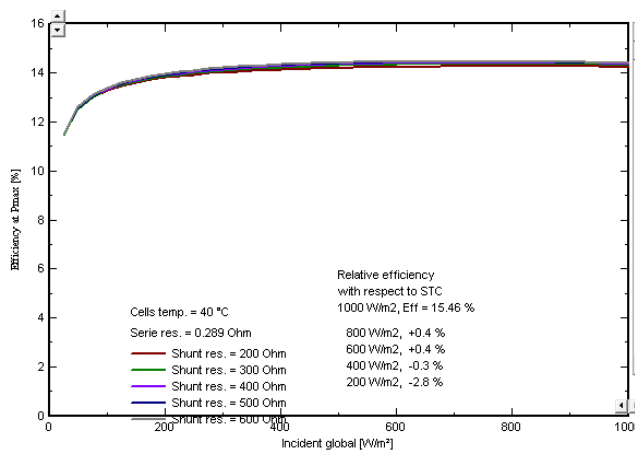


Fig 20. Graph Efficiency vs irradiance

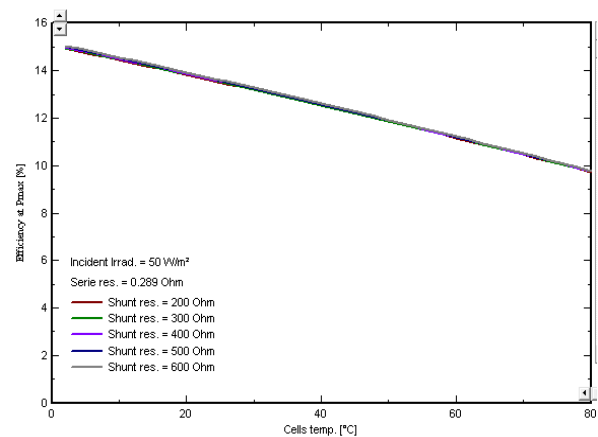


Fig 21. Graph Efficiency vs temperature

Graph parameter: Shunt resistance

red: 200Ω green: 300Ω purple:400Ω blue: 500Ω  
grey : 600Ω

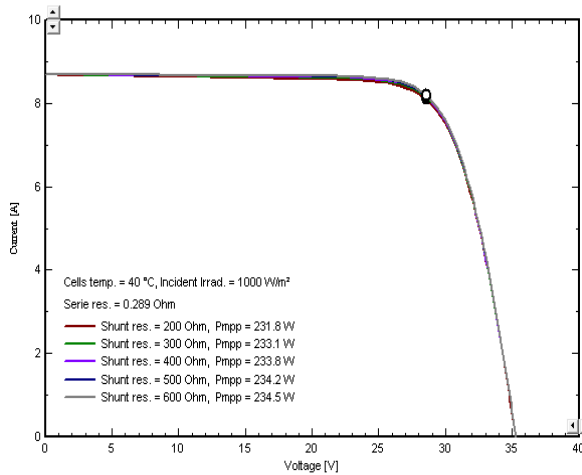


Fig 22. Graph Current vs Voltage

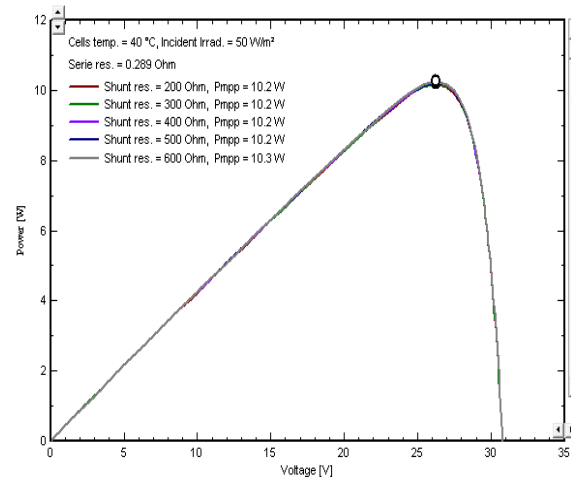


Fig 23. Graph power vs Voltage

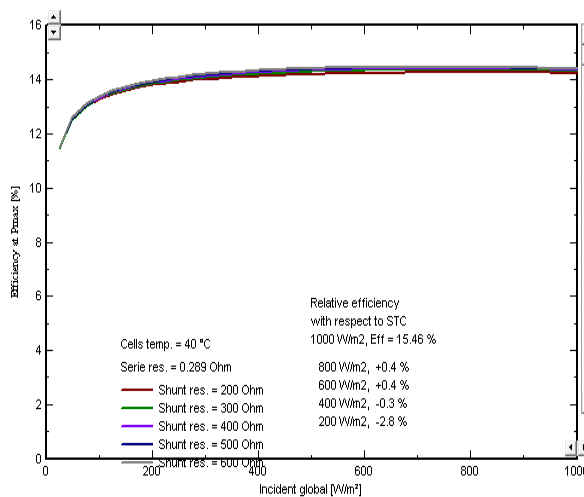


Fig 24. Graph Efficiency vs irradiance

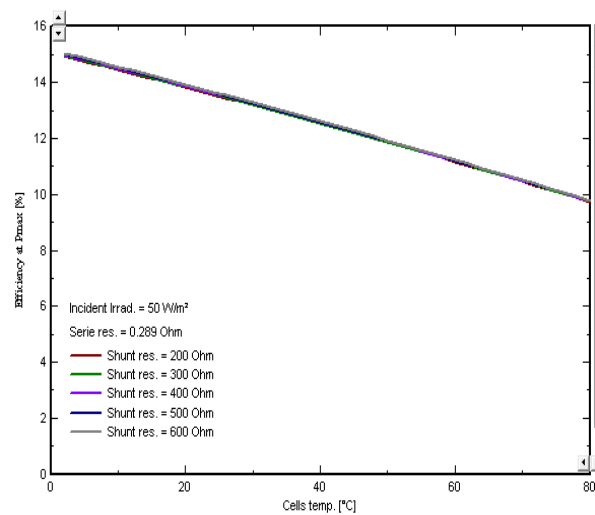


Fig 25. Graph Efficiency vs temperature

g) PV module model optimization

Module Behavior according to incident irradiation ( $\text{W/m}^2$ )

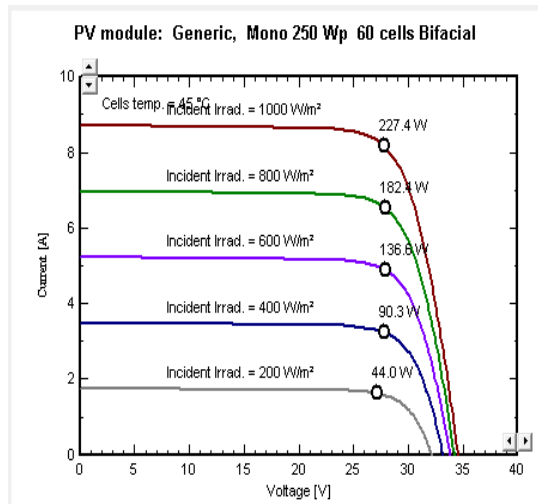


Fig 26. Graph I(V) curves irradiance

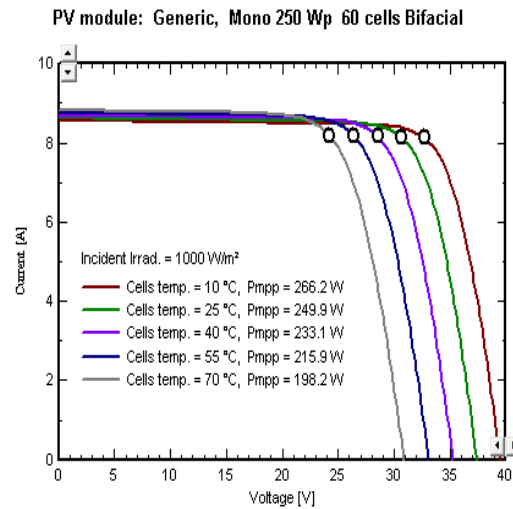


Fig 27. Graph I(V) vs Temperature

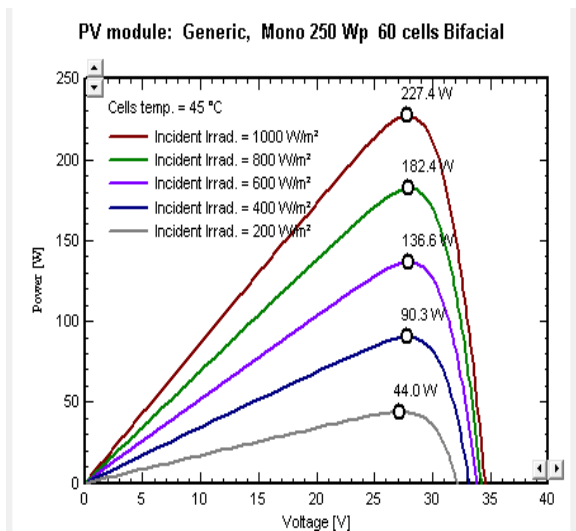


Fig 28. Graph PV curve

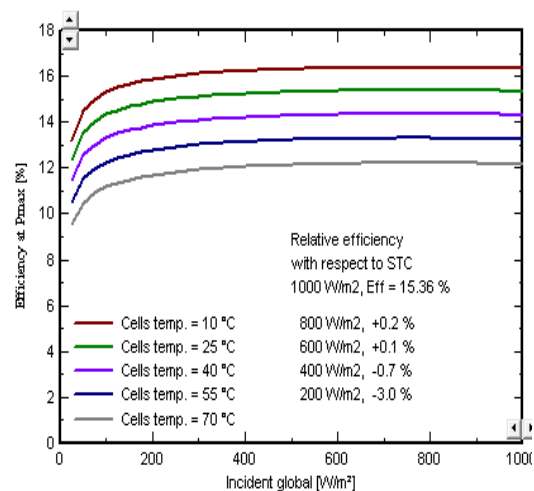


Fig 29. Graph Efficiency vs Irradiance

3) *Solar inverter*

PV inverter is a type of electrical converter which converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. The inverter used in this project is 12kw 350-600v TL 50/60 Hz 12kWac inverter since 2012. 33 of these inverters are connected. The specifications of the inverter are given below.

*Operating Voltage:* 350-600V

*Input maximum Voltage:* 800V

*Global Inverter's power:* 396 kWac

*Input side (DC PV field)*

Minimum MPP voltage: 350V

Nominal MPP Voltage: 450V

Maximum MPP Voltage: 600V

Absolute max. PV Voltage 800V

Minimum Input Current: n/a A

Min. voltage for P<sub>Nom</sub>: n/a V

*Output side (AC grid)*

Triphased

50/60Hz

Grid voltage 400 V

Nominal AC power 12 kVA

Nominal AC current 17A

Maximum AC current 22A

*Contractual specification, Without real Physical meaning*

Nominal PV power 15kw

Maximum PV power 18 kw

Maximum PV current 38A

*Efficiency*

Maximum efficiency 98%

EURO efficiency 97.50%

- a) *Grid inverters - Efficiency curve:* The inverter's efficiency is characterized by a power transfer function during normal operation, depending on the instantaneous power. This transfer is usually given in terms of efficiency as function either of the input or of the output power. That is, it is represented by a non-linear curve, with a threshold input power which may be understood as the inverter's own consumption.

Defining the efficiency curve: The efficiency curve is rarely explicitly given by the manufacturers. For some inverters the database gives the efficiency curve measured by independent institutes.

*Effective output limit:* 12kW

*res factor:* 3

*Threshold efficiency:* 47W

TABLE 2 VALUES OF GRAPH

values	P in (DC)	Efficiency
threshold	0.06	0.00
	0.36	86.61
	0.60	91.73
	1.20	95.53
	2.40	97.31
	3.60	97.81
	7.20	98.00
	12.00	97.66

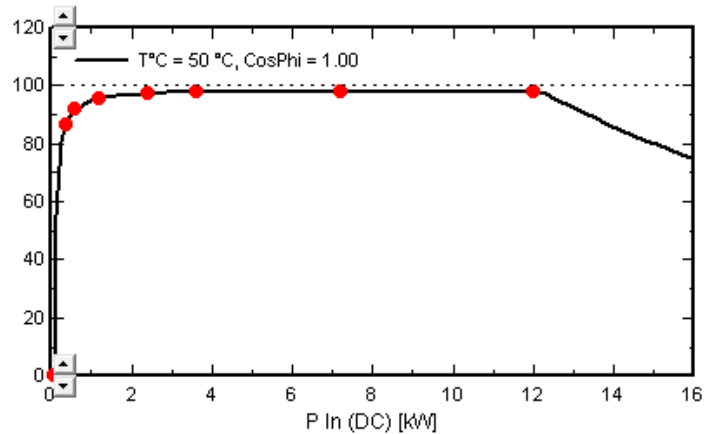


Fig 30. Graph Efficiency graph of inverter

### b) Output parameters of the inverter

The nominal AC power is defined as apparent power(kVA)

- Power factor

Tan (phi) min: -0.395

Tan (phi) Max: 0.395

Maximum AC Power f(temperature)

Nominal ac power 12kVA upto 50°C

Maximum AC Power 14 kVA at 25°C

Power limit #1=9 kwac at 60°C

Power limit absolute =4kwac at 70°C

Temperature evolution for Limits

In the stimulation, by default the inverter temperature is the external ambient temperature (outdoor installation)

### Technology Specificities

Technology: 16 KHz, IGBT

Protection: -25 - +60°C, IP 65:  
outdoor installation

Control: LCD, 2x6 Char.

Generic device DEMO

### Size

Width 468 mm

Depth 242 mm

Height 613mm

Weight 35kg

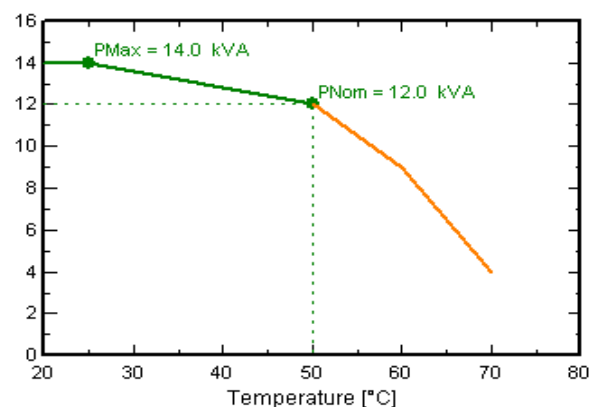


Fig 31. Graph inverter power output

#### 4) Overall PV system

##### Global system summary

Number of modules: 2000

Module area: 3254m<sup>2</sup>

Number of inverter 33

Nominal PV Power 500 kWp

Maximum PV power 476 kWdc

##### Operating condition

V<sub>mpp</sub> (60°C) 411V

V<sub>mpp</sub> (20°C) 502V

V<sub>oC</sub> (-10°) 675V

Plane irradiance 1000 W/m<sup>2</sup>

I<sub>mpp</sub> (STC) 1022 A

I<sub>sc</sub> (STC) 1079 A

Maximum power at 1000W/m<sup>2</sup> 50°C = 443kw

Array nom. Power (STC) 500kW

##### a) Sizing principle

In PVsyst, the inverter sizing is based on an acceptable overload loss during operation, and therefore involves estimations or simulations in the real conditions of the system (meteor, orientation, losses).

Taking the following into account:

Overload behaviour: With all modern inverters, when the P<sub>mpp</sub> of the array overcomes its P<sub>nomDC</sub> limit, the inverter will stay at its safe nominal power by displacing the operating point in the I/V curve of the PV array (towards higher voltages). Therefore it will not undertake any overpower; simply the potential power of the array is not produced. There is no power to dissipate, no overheating and therefore no supplementary ageing. Loss evaluation: In this mode the only energy loss is the difference between the P<sub>mpp</sub> "potential" power and the P<sub>nomDC</sub> limit effectively drawn. We can see on the power distribution diagrams, that even when the inverter's power is a little bit under the maximum powers attained by the array in real operation, this results in very little power losses (violet steps with respect to the green ones, quasi-invisibles). The simulation - and the analysis of the overload loss - is therefore a very good mean for assessing the size of an inverter.

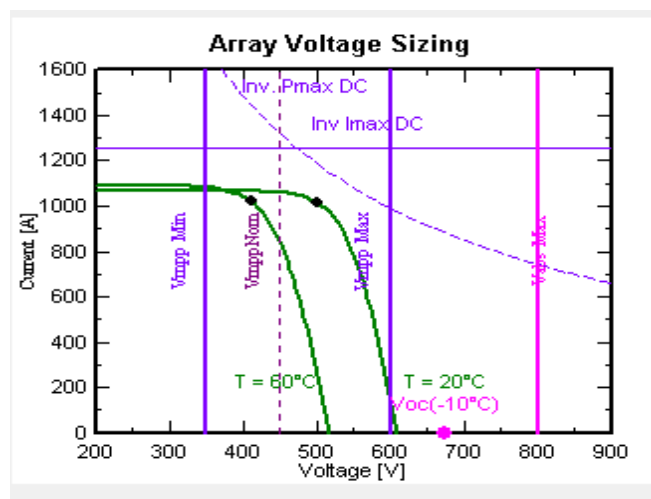


Fig 32. Graph Array Voltage Sizing

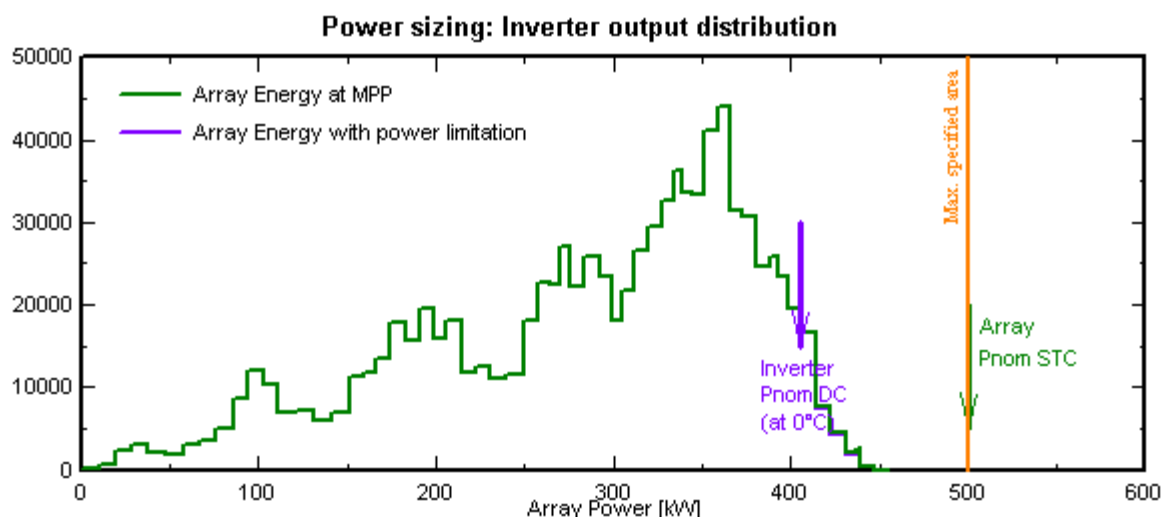


Fig 34. Graph Inverter output distribution AC Energy as  $\text{kW/m}^2$

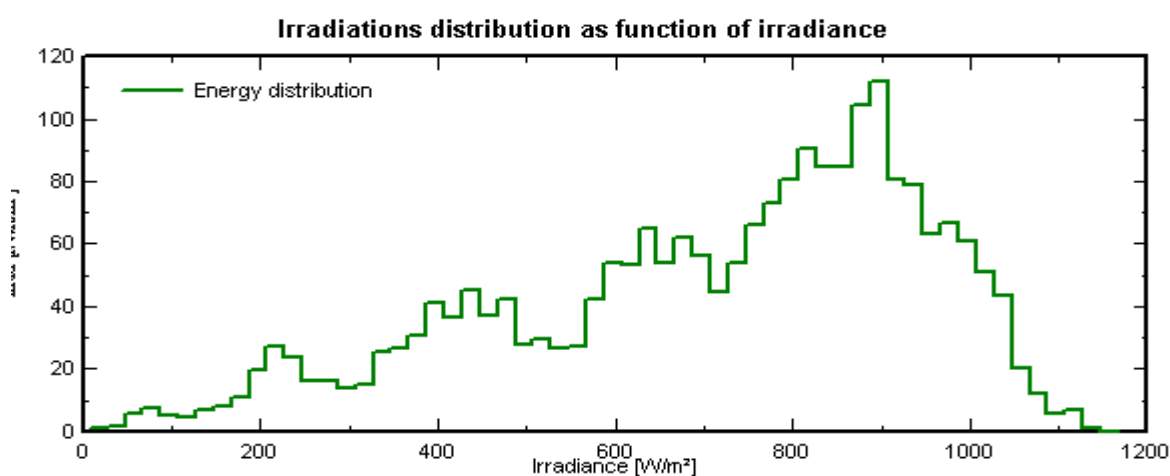


Fig 35. Graph Irradiations distribution as function of irradiance as  $\text{kW/m}^2$

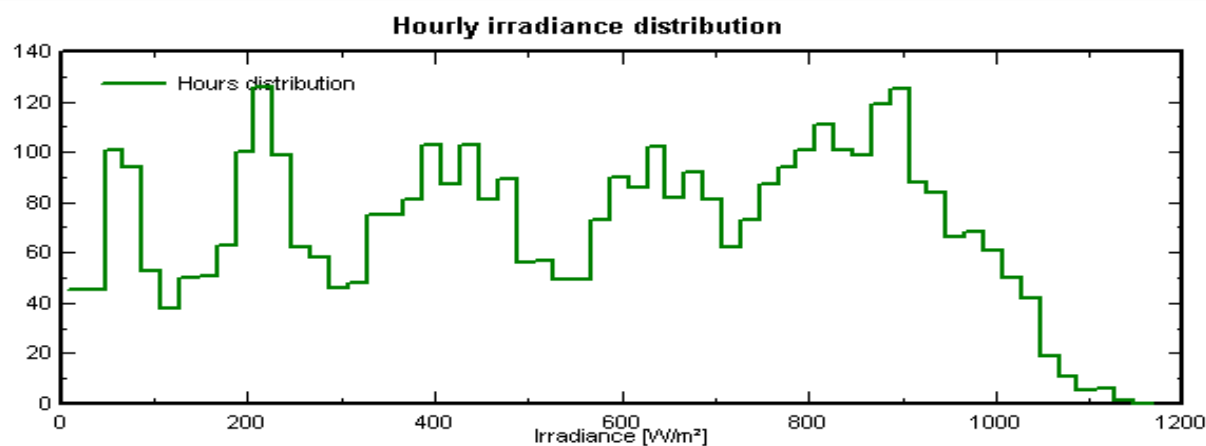


Fig 36. Graph Hourly Distribution of irradiance

D. *Details of Losses:*

While generation of electricity by the solar panel there are numerous factors which can contribute to loss of energy or the generation of current. There are various factors which may include to loss of generations of electricity some of these factors are environmental factors, technical factors, ageing etc

1) *Thermal parameter*

The parameters of the Thermal behavior of the field are defined in the "Array Losses". The thermal behavior of the field - which strongly influences the electrical performances - is determined by an energy balance between ambient temperature and cell's heating up due to incident irradiance.

*Thermal loss factor:*  $U = U_c + U_v \cdot \text{wind velocity}$

*Constant factor loss*  $U_c$ : 20W/m<sup>2</sup>K

*Wind loss factor*  $U_v$ : 0.0 W/m<sup>2</sup>k

2) *Ohmic losses*

Definition: The ohmic resistance of the wiring circuit induces losses ( $E_{\text{Loss}} = R_w \cdot I^2$ ) between the power available from the modules and the power at the terminals of the sub-array. The relevant parameter for the simulation is the  $R_w$  value, which is an equivalent resistance as "seen" from the input of the global sub-array (i.e. the set of MPPT inputs defined in this sub-array). You should define one  $R_w$  value for each sub-array in your system.

*Global wiring resistance:* 7.23mOhm

*Loss fraction at stc* : 1.5%

3) *Module quality loss*

- *Module Quality*

Deviation of the average effective module efficiency with respect to manufacturer specifications (negative value indicates over-performance)

*Module efficiency loss:* -0.8%

- *Module mismatch losses*

The "Mismatch loss" is mainly due to the fact that in a string of modules (or cells), the lowest current drives the current of the whole string.

*Power loss at MPP* : 1%

*Loss when running at a fixed voltage* 2.5%

- *LID-Light Induced Degradation*

LID (Light Induced Degradation) is a loss of performances arising in the very first hours of exposition to the sun, with Crystalline modules. It may namely affect the real performance with respect to the final factory flash tests data delivered by some PV module providers.

*LID loss factor:* 0.0%

- *String voltage mismatch*

The new tool "String Mismatch" (in "Detailed Losses") provides a pedagogic description of the principles of different mismatch modes.

This shows namely that the current mismatch (within a string) is very important, because the current in the whole string is governed by the current in the "weakest" string. While the voltage mismatch between strings has much lower effects.

*Power loss at MPP:* 0.1%

4) *Soiling loss*

Accumulation of dirt and its effect on the system performance is an uncertainty which strongly depends on the environment of the system, raining conditions, etc

Taking into consideration of the dust in the desert region and we are taking an approximate value of 3%



### E. Horizon

The horizon profile may be defined manually by a set of (Azimuth/Height) points in degrees. These may be from on-site measurements (using land-surveyors instruments like compass).

They can also be imported from several sources:

- *Solmetric SunEye instrument*: This is a computerized instrument using a fisheye- type camera for the recording of the environmental masks. It provides an horizon height for each degree of Azimuth (i.e. 360 points).
- *Carnaval*: is a free open source software. It is based on a geo-referred grid for calculating the horizon line at any place between longitudes 6°W to 10°E, and latitudes 41° to 52° N, therefore largely covering France, East of Spain, etc. It uses satellite data from the spatial US programme SRTM (Shuttle Radar Topography Mission), giving a grid of altitudes with a 3" resolution (about 92 x 65 m).

The horizon of far shadings part is the simplest way for defining shadings in PVsyst. But this is only suited for treating shadings of objects sufficiently far, as we can consider they act on the PV field in a global way: at a given instant, the sun is or is not visible on the field. Typically the distance of these shading objects should be higher than, say, ten times the PV field size.

Defining a horizon profile is a very simple operation with the PVsyst graphical tool. The horizon is a broken line superimposed on the sun path diagram, which can hold any number of height/azimuth points.

Horizon measurements (list of height and azimuth of some significant points) can be obtained on-site with a compass and theodolite (clinometer), a detailed map, panoramic or fish-eye photographs, etc

Saving Horizon profile: A horizon profile can be saved for reusing it in another project or meteo calculation. It is stored in the \Shadings\ subdirectory with an extension .HOR.

NB: A file with PVsyst format is not an ASCII file and cannot be exported to other software.

*Hemispherical (horizontal)*

Diffusive factor 1.00

*Tilted plane attenuation factor*

Diffusive factor 1.00

Albedo factor'1.00

TABLE 3 AZIMUTH VS HEIGHT

No.	Azimuth	height
1.	119.2	7.3
2.	-91.4	0.0
3.	92.2	0.0
4.	120.6	8.5

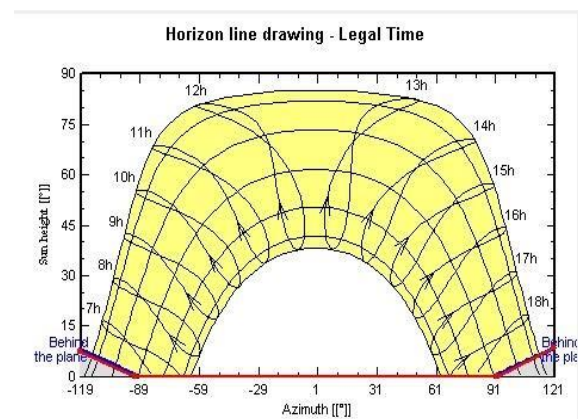


Fig 37. Sun path diagram

### III. RESULT

All the above data is researched and entered into the PVsyst software. After the data is entered into the software, the software runs a stimulation of the data and generates the a report on how the solar will work if it were actual made functional. Thus here is the result and let us analyze the results.

Before we proceed any further, let us look into the specifications of the system again.

The PV modules used are 250Wp 60 cells Bifac.

Inverter used is a 12kW AC inverter. The no of inverters used are 33.

The MPP current and voltage is 8.1 A and 30.7 V. The Nominal power is 500kWp.

#### A. Result overview

The data that we have entered into the software provides us with an overview of the resultant generation of energy. This system is expected to produce about 866 MWh/year and is has a specific production of 1731 kWh/year. A higher Performance Ratio is always desired. The average Performance Ratio that we have been able to achieve using the given configuration is 0.770. The daily production rate of solar energy will be 4.74 kWh/day. An average home in India requires about 10-15 kWh of power per day.

As in every system, there is bound to be some losses, as no system can be 100% efficient. These losses might take place due to inefficient transfer of power, wire losses, etc. Each array is expected to lose 1.31 kWh/day and the system losses is 0.11 kWh/day

The graph above contains sun height on the left axis. The X-axis represents the time of the day. As seen in the graph, Horizontal global irradiation peaks at noon time and continues to rise and fall

uptill 3:00 PM after which there is a steep decline. The same can be seen for the horizontal diffusion irradiation. The Sun Height reaches its peak at around 12 in the noon, after which the output starts to increase.

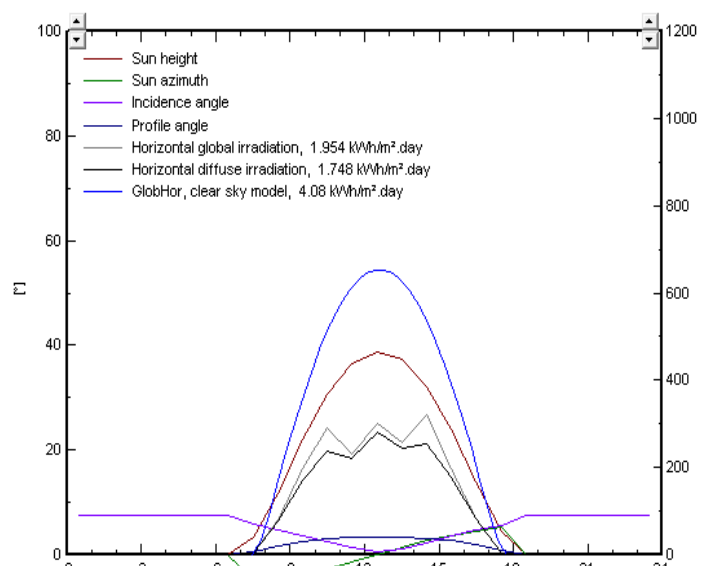


Fig 38. Graph Stimulation variant on hourly basis

#### B. Stimulation variant on hourly basis

The graph in figure 38 gives

Left axis: sun height

Right axis: sun azimuth, Incidence angle, Profile angle, Horizontal diffuse irradiation, Ambient Temperature, Diffuse isotropic-Horizontal, Circumsolar- horizontal, Horizon Band-Vertical

#### C. Stimulation result on monthly basis

PVsyst software generate table on the performance on the solar plant in monthly basis throughout the year

TABLE 4 METEOR AND INCIDENT ENGERGY

	<b>GlobHor</b> kWh/m <sup>2</sup>	<b>DiffHor</b> kWh/m <sup>2</sup>	<b>T_Amb</b> °C	<b>WindVel</b> m/s	<b>GlobInc</b> kWh/m <sup>2</sup>	<b>DifSInc</b> kWh/m <sup>2</sup>	<b>Alb_Inc</b> kWh/m <sup>2</sup>	<b>DifS_GI</b>
<b>January</b>	118.0	36.12	15.28	0.9	185.0	45.25	3.748	0.000
<b>February</b>	137.3	36.34	19.50	1.2	189.0	44.42	4.363	0.000
<b>March</b>	178.3	54.86	25.70	1.4	201.0	58.43	5.667	0.000
<b>April</b>	194.6	71.68	30.60	1.6	202.3	74.03	0.754	0.000
<b>May</b>	204.8	94.84	35.42	2.5	202.2	94.62	0.793	0.000
<b>June</b>	191.0	97.98	34.67	2.6	185.1	96.25	0.739	0.000
<b>July</b>	172.4	94.58	33.33	2.4	168.3	93.13	0.668	0.000
<b>August</b>	170.0	93.25	32.12	2.0	171.6	93.72	0.659	0.000
<b>September</b>	165.8	66.11	31.09	1.4	178.1	68.92	0.640	0.000
<b>October</b>	150.8	55.35	28.63	0.9	189.9	61.54	4.793	0.000
<b>November</b>	124.0	34.75	22.19	0.7	188.5	43.08	3.938	0.000
<b>December</b>	113.2	31.20	17.25	0.7	188.8	41.56	3.589	0.000
<b>Year</b>	1920.3	767.06	27.18	1.5	2249.7	814.95	30.351	0.000

TABLE 5 EFFECTIVE INCIDENT ENERGY

	<b>GlobHor</b> kWh/m <sup>2</sup>	<b>GlobInc</b> kWh/m <sup>2</sup>	<b>GlobHrz</b> kWh/m <sup>2</sup>	<b>GlobIAM</b> kWh/m <sup>2</sup>	<b>GlobSlg</b> kWh/m <sup>2</sup>	<b>GlobEff</b> kWh/m <sup>2</sup>	<b>DiffEff</b> kWh/m <sup>2</sup>
<b>January</b>	118.0	185.0	185.0	182.0	176.5	176.5	42.11
<b>February</b>	137.3	189.0	189.0	185.4	179.9	179.9	41.34
<b>March</b>	178.3	201.0	201.0	195.6	189.7	189.7	54.37
<b>April</b>	194.6	202.3	202.3	196.3	190.4	190.4	68.36
<b>May</b>	204.8	202.2	202.1	195.2	189.4	189.4	87.37
<b>June</b>	191.0	185.1	185.0	178.5	173.1	173.1	88.88
<b>July</b>	172.4	168.3	168.2	162.1	157.2	157.2	86.00
<b>August</b>	170.0	171.6	171.6	165.5	160.5	160.5	86.54
<b>September</b>	165.8	178.1	178.1	172.3	167.1	167.1	63.64
<b>October</b>	150.8	189.9	189.9	185.4	179.9	179.9	57.28
<b>November</b>	124.0	188.5	188.5	185.3	179.8	179.8	40.09
<b>December</b>	113.2	188.8	188.8	186.1	180.5	180.5	38.68
<b>Year</b>	1920.3	2249.7	2249.5	2189.7	2124.0	2124.0	754.66

TABLE 6 OPTICAL FACTOR

	<b>GlobHor</b> kWh/m <sup>2</sup>	<b>GlobInc</b> kWh/m <sup>2</sup>	<b>FTransp</b>	<b>FIAMBm</b>	<b>FIAMGI</b>	<b>FIAMShd</b>
<b>January</b>	118.0	185.0	1.567	0.992	0.984	0.984
<b>February</b>	137.3	189.0	1.376	0.989	0.981	0.981
<b>March</b>	178.3	201.0	1.127	0.979	0.973	0.973
<b>April</b>	194.6	202.3	1.039	0.982	0.970	0.970
<b>May</b>	204.8	202.2	0.987	0.981	0.966	0.966
<b>June</b>	191.0	185.1	0.969	0.981	0.965	0.965
<b>July</b>	172.4	168.3	0.976	0.980	0.963	0.963
<b>August</b>	170.0	171.6	1.009	0.982	0.964	0.964
<b>September</b>	165.8	178.1	1.074	0.979	0.968	0.968
<b>October</b>	150.8	189.9	1.259	0.985	0.976	0.976
<b>November</b>	124.0	188.5	1.520	0.991	0.983	0.983
<b>December</b>	113.2	188.8	1.668	0.993	0.985	0.985
<b>Year</b>	1920.3	2249.7	1.172	0.985	0.973	0.973

TABLE 7 DETAILED LOSSES IN A SYSTEM

	<b>ModQual</b> kwh	<b>MisLoss</b> kwh	<b>OhmLoss</b> kwh	<b>EArrMPP</b> kwh	<b>InvLoss</b> kwh
<b>January</b>	-593.278	876.6	950	77869	1777
<b>February</b>	-585.917	865.8	1014	76828	1750
<b>March</b>	-601.972	889.5	1011	78964	1810
<b>April</b>	-589.528	871.1	993	77331	1796
<b>May</b>	-578.028	854.1	913	75882	1729
<b>June</b>	-536.417	792.7	789	70478	1603
<b>July</b>	-493.972	729.9	679	64948	1520
<b>August</b>	-507.611	750.1	704	66736	1559
<b>September</b>	-522.861	772.6	818	68647	1580
<b>October</b>	-564.750	834.5	927	74103	1676
<b>November</b>	-578.028	854.1	1000	75795	1728
<b>December</b>	-597.917	883.5	994	78442	1761
<b>Year</b>	-6750.278	9974.6	10793	886022	20289

TABLE 8 DETAILED INVERTER LOSSES

	<b>EOutInv</b> kwh	<b>EffInvR</b> %	<b>InvLoss</b> kwh	<b>IL_Oper</b> kwh	<b>IL_Pmin</b> kwh	<b>IL_Pmax</b> kwh	<b>IL_Vmin</b> kwh	<b>IL_Vmax</b> kwh	<b>IL_Imax</b> kwh
<b>January</b>	76092	97.7	1777	1772	4.680	0.000	0.000	0.000	0.000
<b>February</b>	75077	97.7	1750	1748	2.107	0.000	0.000	0.000	0.000
<b>March</b>	77154	97.7	1810	1807	3.245	0.000	0.000	0.000	0.000
<b>April</b>	75535	97.7	1796	1795	0.818	0.000	0.000	0.000	0.000
<b>May</b>	74153	97.7	1729	1729	0.000	0.000	0.000	0.000	0.000
<b>June</b>	68875	97.7	1603	1603	0.393	0.000	0.000	0.000	0.000
<b>July</b>	63428	97.7	1520	1520	0.000	0.000	0.000	0.000	0.000
<b>August</b>	65177	97.7	1559	1558	0.694	0.000	0.000	0.000	0.000
<b>September</b>	67067	97.7	1580	1571	9.389	0.000	0.000	0.000	0.000
<b>October</b>	72427	97.7	1676	1676	0.000	0.000	0.000	0.000	0.000
<b>November</b>	74066	97.7	1728	1727	1.824	0.000	0.000	0.000	0.000
<b>December</b>	76682	97.8	1761	1756	4.692	0.000	0.000	0.000	0.000
<b>Year</b>	865733	97.7	20289	20261	27.842	0.000	0.000	0.000	0.000

TABLE 9 BALANCE AND MAIN RESULTS

	<b>GlobHor</b> kWh/m <sup>2</sup>	<b>DiffHor</b> kWh/m <sup>2</sup>	<b>T_Amb</b> °C	<b>GlobInc</b> kWh/m <sup>2</sup>	<b>GlobEff</b> kWh/m <sup>2</sup>	<b>EArray</b> kWh	<b>E_Grid</b> kWh	<b>PR</b>
<b>January</b>	118.0	36.12	15.28	185.0	176.5	77869	76092	0.823
<b>February</b>	137.3	36.34	19.50	189.0	179.9	76828	75077	0.795
<b>March</b>	178.3	54.86	25.70	201.0	189.7	78964	77154	0.768
<b>April</b>	194.6	71.68	30.60	202.3	190.4	77331	75535	0.747
<b>May</b>	204.8	94.84	35.42	202.2	189.4	75882	74153	0.734
<b>June</b>	191.0	97.98	34.67	185.1	173.1	70478	68875	0.744
<b>July</b>	172.4	94.58	33.33	168.3	157.2	64948	63428	0.754
<b>August</b>	170.0	93.25	32.12	171.6	160.5	66736	65177	0.760
<b>September</b>	165.8	66.11	31.09	178.1	167.1	68647	67067	0.753
<b>October</b>	150.8	55.35	28.63	189.9	179.9	74103	72427	0.763
<b>November</b>	124.0	34.75	22.19	188.5	179.8	75795	74066	0.786
<b>December</b>	113.2	31.20	17.25	188.8	180.5	78442	76682	0.812
<b>Year</b>	1920.3	767.06	27.18	2249.7	2124.0	886022	865733	0.770

TABLE 10 ENERGY USAGE

	E_Grid kwh	PR
January	76092	0.823
February	75077	0.795
March	77154	0.768
April	75535	0.747
May	74153	0.734
June	68875	0.744
July	63428	0.754
August	65177	0.760
September	67067	0.753
October	72427	0.763
November	74066	0.786
December	76682	0.812
Year	865733	0.770

D. The result report produced by the software

The PVsyst software produces detailed report of the solar plant which shows in details about the about various aspects on the solar power plant.

PVSYST V6.81			28/08/20	Page 1/5				
Grid-Connected System: Simulation parameters								
Project : solar power plant								
Geographical Site		Asâsar	Country	India				
Situation		Latitude	28.29° N	Longitude	74.23° E			
Time defined as		Legal Time	Time zone UT+5.5	Altitude	249 m			
		Albedo	0.20					
Meteo data:		Asâsar	Meteonorm 7.2 (1981-2010), Sat=100% - Synthetic					
Simulation variant : New simulation variant								
		Simulation date	26/07/20 18h56					
Simulation parameters		System type	Sheds system, seasonal tilt					
Coll. plane: Seasonal tilt adjustment		Azimuth	0°	Winter season	O-N-D-J-F-M			
		Summer Tilt	16°	Winter Tilt	47°			
Models used		Transposition	Perez	Diffuse	Perez, Meteonorm			
Horizon		Average Height	0.9°					
Near Shadings		No Shadings						
User's needs :		Unlimited load (grid)						
PV Array Characteristics								
PV module		Si-mono	Model	Mono 250 Wp 60 cells Bifacial				
Original PVsyst database		Manufacturer	Generic					
Number of PV modules		In series	16 modules	In parallel	125 strings			
Total number of PV modules		Nb. modules	2000	Unit Nom. Power	250 Wp			
Array global power		Nominal (STC)	500 kWp	At operating cond.	443 kWp (50°C)			
Array operating characteristics (50°C)		U mpp	434 V	I mpp	1022 A			
Total area		Module area	3254 m²	Cell area	2844 m²			
Inverter		Model	12 kWac inverter					
Original PVsyst database		Manufacturer	Generic					
Characteristics		Operating Voltage	350-600 V	Unit Nom. Power	12.0 kWac			
				Max. power (=>25°C)	14.0 kWac			
Inverter pack		Nb. of inverters	33 units	Total Power	396 kWac			
				Pnom ratio	1.26			
PV Array loss factors								
Array Soiling Losses		Uc (const)	20.0 W/m²K	Loss Fraction	3.0 %			
Thermal Loss factor				Uv (wind)	0.0 W/m²K / m/s			
Wiring Ohmic Loss		Global array res.	7.2 mOhm	Loss Fraction	1.5 % at STC			
Module Quality Loss				Loss Fraction	-0.8 %			
Module Mismatch Losses				Loss Fraction	1.0 % at MPP			
Strings Mismatch loss				Loss Fraction	0.10 %			
Incidence effect (IAM): Fresnel smooth glass, n = 1.526								
0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

Fig 39. Report 1

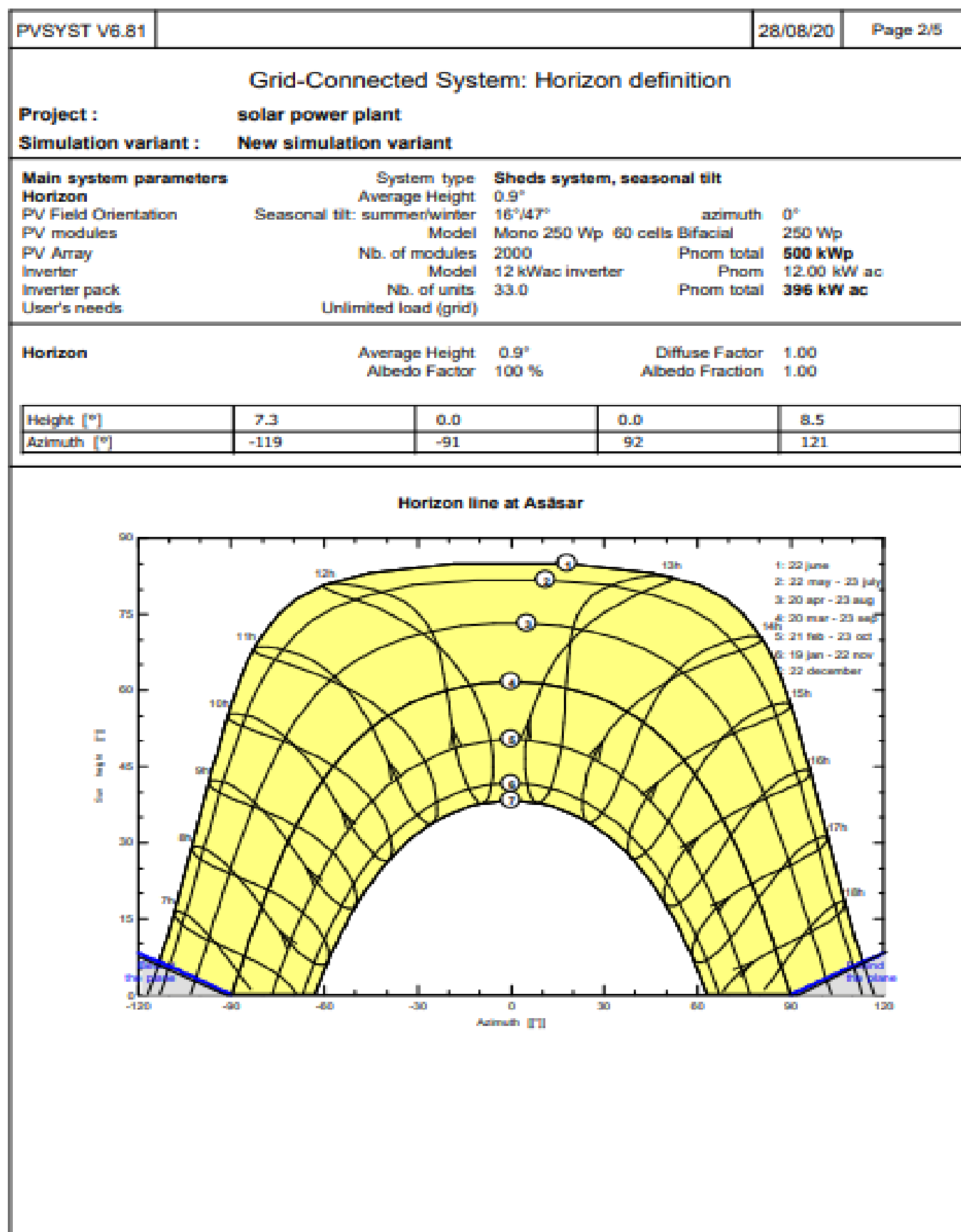


Fig 40. Report 2

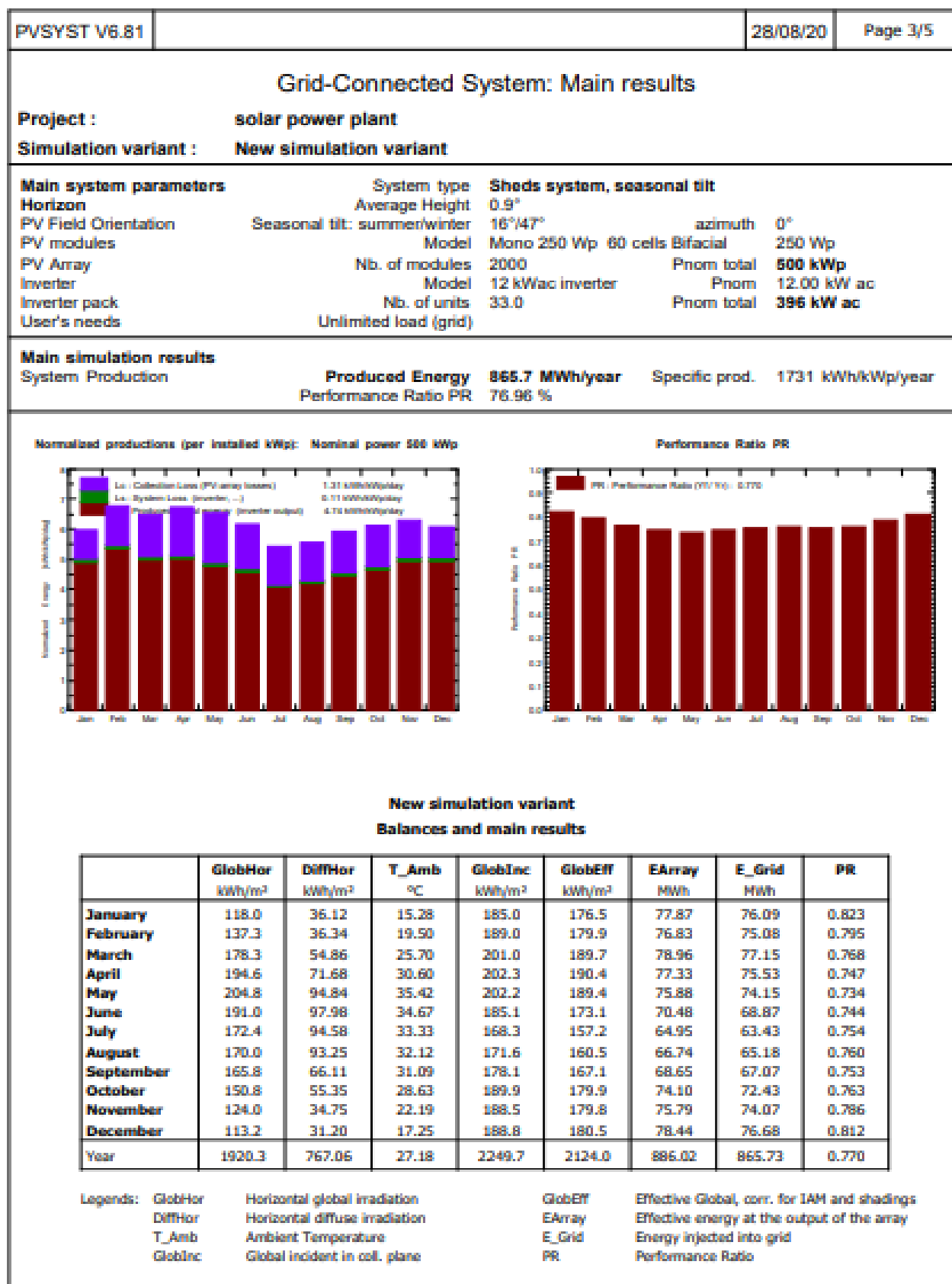


Fig 41. Report 3

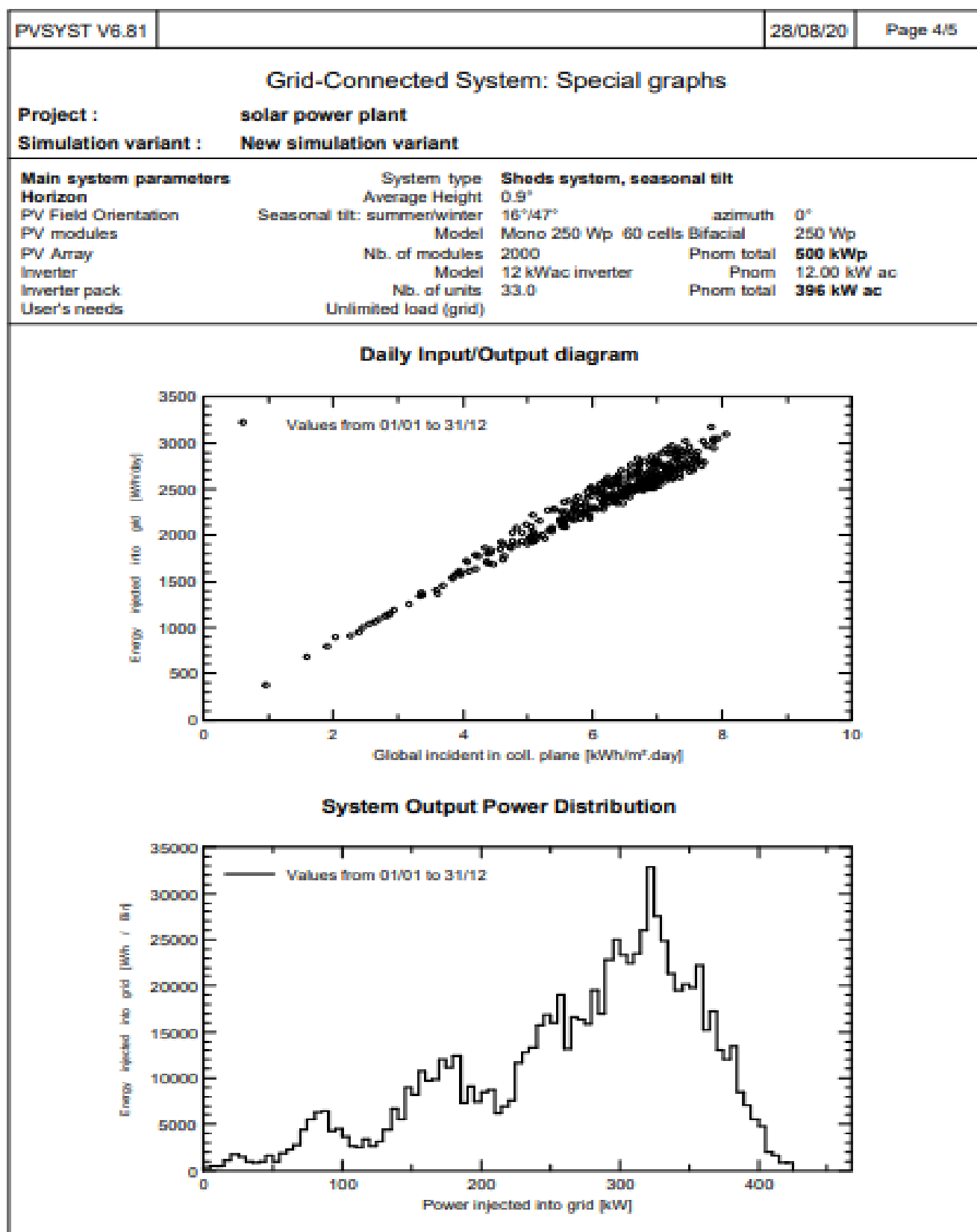


Fig 42. Report 4



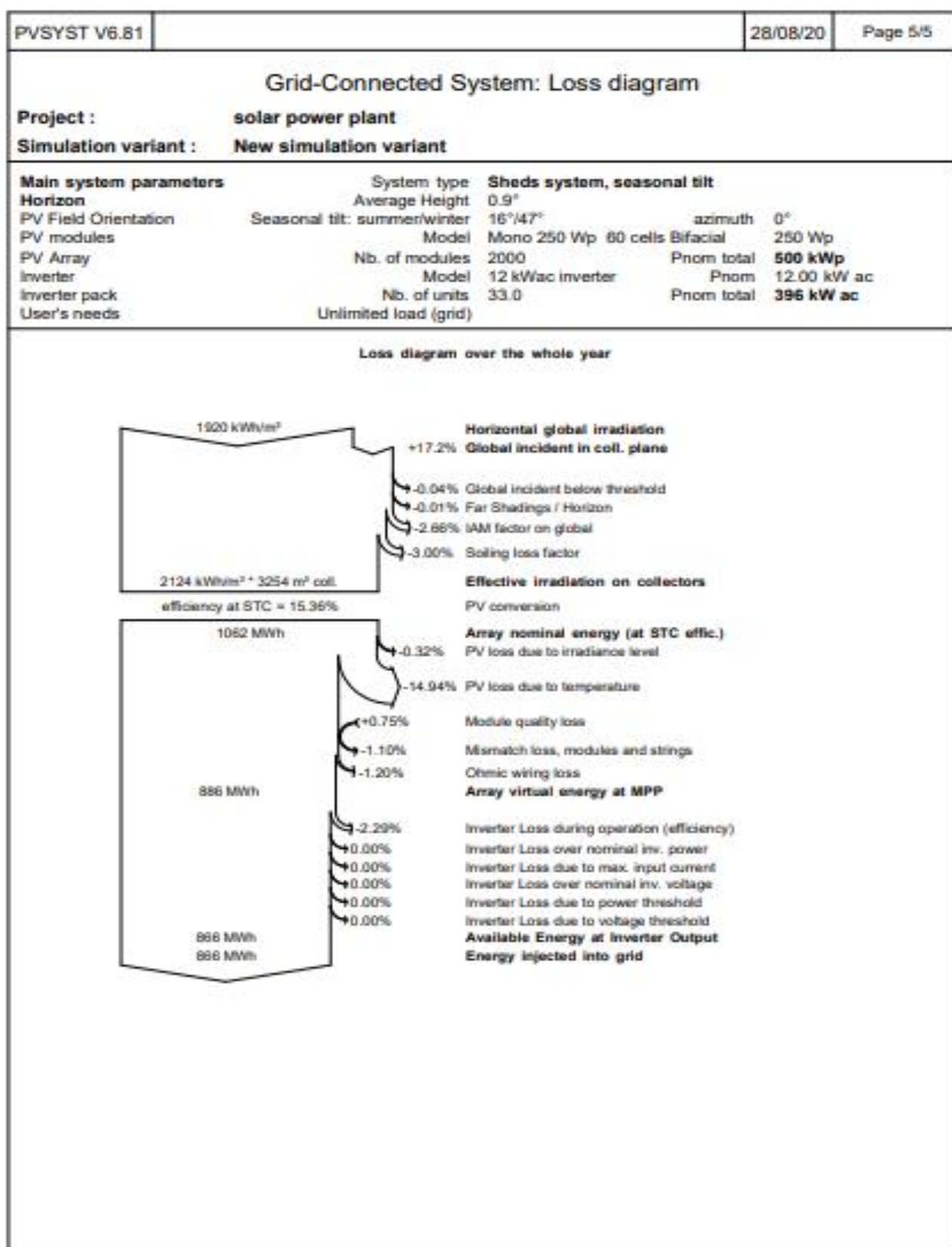


Fig 43. Report 5

#### IV. CONCLUSION

As per the results that we have derived with the help of PVsyst, constructing a 500 kW power plant in Asasar is deemed feasible. The average cost of such a power plant will be around the range of Rs. 2 crore. Constructing a coal based power plant of the same power will cost much more and will be detrimental in the long run. Solar power generation is yet to be perfected, but based on the history of the accomplishments of mankind, it's only a matter of time and patience. The sooner we shift towards renewable sources of energy, lesser the chances of us causing irreparable damage to the environment.

#### V. SUMMARY

The paper explains in detail about a 500kw solar power plant in Asasar, Rajasthan. It explains in detail about the PV module used, the inverter and the losses that may occur during the running of the solar power plant. There are 16 modules in series and 125 strings in this power plant spread across an area of 3254 m<sup>2</sup>. The module and the inverter is properly studied and researched and explained with proper graph. The different types of probable factors of loss are studied and explained in this paper. The PVsyst software uses data from Meteonorm and other sites to for the various weather conditions which are explicitly described in the paper. Since the site is made on a desert there is no possibility of shadow therefore there is no near shading given to the software. The horizon and the sun path in that region are also calculated and the data is given to the software. Then the software has a feature of running stimulation based of the data entered. The result of the stimulation gives the various data month in a year and also hourly in a day. The report given by the software is given in the paper and also it is explained.

#### VI. SCOPE OF THE PROJECT

The project report is prepared considering limited time, resources and maintaining strict social distancing requirements. Due to increase in the price of fossil fuel, carbon emission, draining of foreign exchange and depletion of coal resources, Government of India(GOI) has taken decisive steps towards increasing alternative energy sources. A decision was taken by GOI to bring down crude oil import by 10%. Amongst others, special impetus was given for development of solar energy across India.

#### VII.

There has been a steady growth of installed capacity of solar PV as depicted in the graph. With cases schemes like Atma Nirbhar bharat and solar power plant in Rewa the is a huge scope of this project. This is going to create jobs and provide energy to household and also taking care of the environment.

#### ACKNOWLEDGEMENT

First of all, we would like to express my special gratitude to our university, Delhi Technological University, the Vice Chancellor, Professor Yogesh Singh sir and to our professor who guided us through the project, Professor J.P Kesari sir, for providing us the necessary help. We also thank our friends and colleagues for their contribution and advice. We owe the completion of this paper within the limited time to all of them. The research the we did for the project has increased our knowledge to a great extent and has made us more informed on the topic.

#### APPENDIX

*GOper*- This is the internal model result tool of the PV module. It gives information about the operating characteristic which says about the power per meter square.

*TOper*- This is the internal model result tool of the PV module. It gives information about the operating characteristic which says about the operating temperature.

*Isc*-(short circuit current) Short Circuit Current is how many amps (i.e. current) the solar panels are producing when not connected to a load but when the plus and minus of the panels wires are directly connected to each other.

*mpp/Pmax*- (Maximum Power Point) it is the sweet spot of the solar panel power output, located at the "knee" of the curves in the graph above. It is where the combination of the volts and amps results in the highest wattage (Volts x Amps = Watts).

*VoC*-( Open circuit volatage) Open circuit voltage is how many volts the solar panel outputs with no load on it. If you just measure with a voltmeter across the

plus and minus leads, you will read Voc. Since the solar panel isn't connected to anything, there is no load on it, and it is producing no current.

Si-mono- Monocrystalline silicon, more often called single-crystal silicon.

**STC-** (Standard Test Conditions) STC is the set of criteria that a solar panel is tested at. Since voltage and current change based on temperature and intensity of light, among other criteria, all solar panels are tested to the same standard test conditions.

**ImpP-** (Maximum Power Point Current) The ImpP is the current (amps) when the power output is the greatest. It is the actual amperage you want to see when it is connected to the MPPT solar equipment under standard test conditions.

**VmPP-** (Maximum Power Point Voltage ) The VmPP is the voltage when the power output is the greatest. It is the actual voltage you want to see when it is connected to the MPPT solar equipment (like an MPPT solar charge controller or a grid-tie inverter) under standard test conditions.

**Gref and Tref-** The Gref and Tref are the values for definition of the model according to Isc, Voc, ImpP, VmPP (normally the STC values)

**ASCII-** American Standard Code for Information Interchange

**BRev-** it is the quadratic factor for reverse characteristics

**Nominal voltage-** is defined as a value assigned to a circuit or system for the purpose of conveniently designating its voltage class

**IGBT-** insulated-gate bipolar transistor

**Pnom-** nominal power

**PnomDC-** nominal power of DC current

**muIsc, muPMax, muVoC-** The temperature behavior of the Pmpp, Voc and Isc values (at STC) are usually specified on the manufacturer's datasheets. In PVsyst we denote by the prefix "mu" all temperature coefficients

## REFERENCES

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