Advanced Research in Electrical and Electronic Engineering
Print ISSN: 2349-5804; Online ISSN: 2349-5812 Volume 1, Number 4 (2014) pp. 19-25

http://www.krishisanskriti.org/areee.html

Performance Analysis of Stand-alone PV Systems Under Non-Uniform Operating Conditions Using PVsyst

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Abstract: **As the electrical energy consumption goes on increasing, there will be a continuous demand to increase the power generation from the renewable resources. Among different forms of renewable energy, the solar photovoltaic systems are growing in a fast rate in the recent years. The performance of the PV systems are characterized by various parameters like solar irradiance, temperature, wind speed and so on. Since a single PV cell produces only 0.7V, we need to connect a number of cells in series to form a solar photovoltaic array to produce the required voltage levels of practical applications. It is very difficult to maintain the solar insolation at a constant rate at all times and this affect the performance of the PV array. Under non-uniform insolated conditions such as partial shading of the cells such as near shadings, far shadings due to passing of clouds, shadows caused by buildings etc., the P-V as well as the I-V characteristics become more complex having multiple peaks. The paper describes the design of standalone PV systems with the field losses considerations in Thiruvananthapuram. The simulations are done by using PVsyst, a software package for the analysis and simulation of a complete PV systems.**

Keywords: **solar photovoltaic array, solar insolation, field losses, PVsyst software**

1. INTRODUCTION

As concerns grow over the increasing effects of the burning fuels, increasing effects are made to produce the electrical energy from the sun. No other renewable energy resource offers much potential to empower the entire civilization. The sun is a tremendous energy source; infact the earth surface receives enough energy from the sun in one hour to meet the energy requirement in one year. The small scale residential and commercial grid tied photovoltaic systems have greater popularity due to the new and flexible module designs which is economical. The government and the utilities also give incentives favouring solar technologies. The system will operate at its maximum possible efficiency only under uniform operating conditions. The performance of the PV systems are always characterized by various parameters such as geographical location, panel orientation, mounting structure, climatic conditions etc. The design discussed is for grid connected PV systems for the geographical location, Thiruvananthapuram in Kerala with the field loss considerations.

2. PV PERFORMANCE FACTORS

The factors affecting PV performance are summarizes as follows:

a) Temperature : The efficiency of the photovoltaic cell increases by producing high currents at cold temperatures. Also the voltage across the photovoltaic cell increases by 0.3-0.5% for every degree Celsius below 25^0C. In temperature climates, PV will generate less energy in winter than in summer, but this is due to the shorter days, lower sun angles, greater cloud cover, not the cooler temperatures.

b) Seasonality : The Thiruvananthapuram city receives about 5.38 hours of sunlight per day.

c) Partial Shading : The effect of shade on power output of a typical PV installations is non-linear. A small amount of shade on a portion of the array can cause a large reduction in the output power.

d) Soiling : Any material deposited on the PV module glass which interferes with the incoming radiation will adversely affect the power generating potential of the module. Most often taking the form of dust and snow, the magnitude of soiling losses depends heavily on the climate of the installation site.

e) System Voltage: PV cells operate at a relatively stable voltage. The current and power output of photovoltaic modules is approximately proportional to the solar insolation.

f) Aging : The output of any PV module will drop gradually over the course of its lifetime once the initial break-in period has elapsed.

3. STAND-ALONE PV SYSTEM DESIGN

A. Introduction: The stand-alone PV systems sometimes called as off-grid systems are designed to provide electricity to home without drawing any supplementary power the utility grid. In the off-grid PV systems, PV is frequently used for charging the batteries, thus storing the electrical energy produced by the modules and providing the user with electrical energy on demand.

In the case of residential or building mounted stand-alone PV systems, the electricity demand of the building is mainly met by the PV system. The excess is fed into the battery for storage. The feeding of electricity into the stand-alone equipments requires the transformation of DC into AC by an inverter. A back-up generator is required in case of emergency.

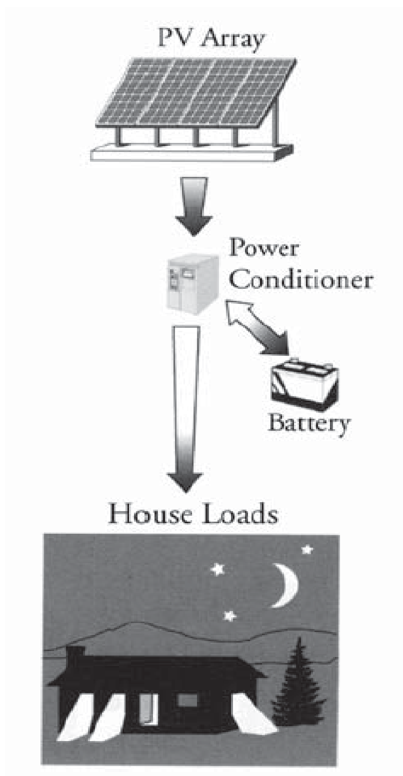


Figure 1. Stand-alone PV system schematic

B. **PVsyst:** Among the various software programs, PVsyst simulation software is the most popular. This software gives the detailed performance of the PV plants under operating as well as non- uniform operating conditions. It can be also used to investigate different loads on the system, to estimate the size of the system, to determine the optimal size of the panel, and to assess the energy production in the system. It can evaluate hourly, monthly as well as yearly energy production and performance. It also performs economic evaluation of the PV system at the design stage itself. Its application performs a detailed simulation and shading analysis according to many variables. PVsyst also considers the shading of a diffuse radiation. The limitation of the software is that it can compute only a single layer of PV module[4]. This means that if there are two layers of PV modules, one above the other, the software has no provision or option to compute the solar energy. Apart from the PVsyst, there are about twelve other software tools currently in use for the simulation e.g., PV F-Chart, SOLCEL-II, PVSIM, PVFORM, TRNSYS, PVLab, PVSS, RETSCREEN, Renew, SimPhoSys, PVSOL Expert, HOMER, SolarPro etc.

C. Components of PV systems

The stand-alone PV system consists of PV generator, battery, controller, inverter and load.

(1) *Solar Panels (PV) Modules* : Most of the stand-alone PV systems need to be managed properly. The user should know the limitations of a system, the energy consumption according to how sunny it is as well as the state of charge (SOC) of the battery. The solar panels need to be configured in-order to match the system DC voltage, which is determined by the battery. The system voltages are typically, 12V DC and 24V DC.

(2) *Charge Controllers* : The charge controllers are designed to protect the battery from over-charging and over-discharging normally referred to as low voltage disconnect (LVD) that disconnects the battery from the load when the battery reaches a certain depth of discharge (DOD) and to ensure that the system has a long working life without affecting the efficiency.

(3) *Batteries*: The power requirements of stand-alone PV systems are rarely in synchronized with the battery charging. Appliances and loads need to be powered when there is sufficient solar irradiation, during overcast weather and during the night. Under ideal conditions, a new deep-cycle battery would be 90% efficient. The important characteristics to look for are: Capacity, cycle life, price /performance, size and space requirements, Ah efficiency, self-discharge rate, installation etc.

(4) *Cables and Accessories*: Cables need to be ultra-violet resistant and suitable for outdoor applications. It is very important to keep power losses and voltage drop in the cable to a minimum.

D. Design

The stand-alone PV system design procedure is as follows. There are few steps that need to be taken while designing a stand-alone PV systems and the following steps are preferred.

(1) Determination of the Load

Appliances	Rated wattage	Adjustment factor	Adjusted wattage	Hours/day used	Energy/day
30W light(5)	150	0.85	176	2	352
45W fans (3)	135	085	588	5	2940
Refrigerator	500	0.85	159	8	1272
Washing machine	1500	0.85	1765	0.86	1518
Television	200	0.85	235	4	940
Microwave oven	1500	0.85	1765	0.25	441

Total energy demand per day = 7468Wh

(2) Sizing of the battery : The battery should be able to handle the load. So the battery capacity requirement is as follows.
Required battery capacity = (total amp-hr per day × days of storage)/ allowable depth of discharge = 2721 Ah
Amp- hr of the selected battery = 478Ah
No. of batteries in parallel =required battery capacity/amp-hr capacity of the battery = 6
No. of batteries in series = battery bus voltage/ selected battery voltage = 2

Total battery amp-hr capacity = no. of batteries in parallel × amp- hr capacity of the selected battery = 2868Ah

(3) Determination of solar radiation for the site location.

	Gl. horiz. kWh/m².day
Jan.	5.66
Feb.	6.16
Mar.	6.54
Apr.	6.07
May	5.49
June	4.57
July	5.12
Aug.	5.47
Sep.	5.72
Oct.	5.36
Nov.	4.82
Dec.	5.18
Year	5.51

Figure.2 Monthly irradiance data

(4) PV Array Sizing : If the system is going to be used all year round and the energy requirement is fairly constant then the design is as follows.
No. of modules required to meet the energy demands = Total energy demand per day/battery efficiency/module energy output at operating temperature = 54
No. of modules per string = battery voltage/selected PV maximum power voltage = 2
No. of strings = total no. of modules/ no. of modules per string = 27

Project : For the stand-alone PV system, the basic parameters required for modeling are the following - PV component database includes open circuit voltage, short circuit current, shunt as well as series resistances and a set of constants, inverter database consists of required voltage and power ratings, geographical site information includes latitude, longitude, altitude etc, and monthly meteorological data for horizontal global irradiance and temperature. In the present study, the meteorological data is acquired from Meteonorm version 6.1.0.23, a comprehensive climatological database for solar energy applications.

(1) Location : In the project part, the geographic location defined is Thiruvananthapuram. PVsyst includes its own solar data for some locations.

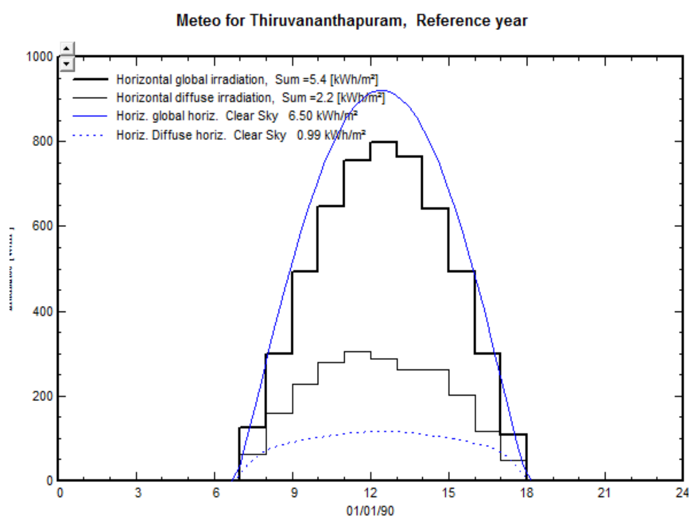


Figure.3 Graphs of meteo hourly data

(2) Orientation : In the orientation part, the panels are facing (south for this study case), and the angle the panels will form with the ground (the inclination or tilt angle) are set. The energy usage between winter time and summer time is big, otherwise at this latitude, the solar resource gap between winter and summer is not that big. That is the reason why the inclination needs to be optimized for the summer months. Here the plane tilt is about 30^0 and azimuth is about 20^0 .

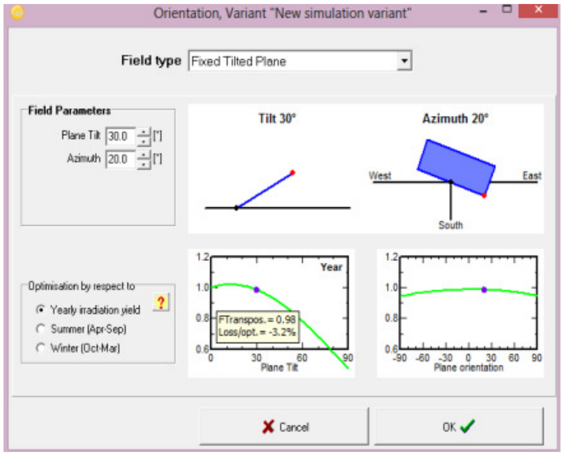


Figure 4.Tilting and orientation of PV panel

(3) Horizon : The horizon part indicates how much useful sun is actually available. The red line indicates obstacles around the solar field mainly distant trees while blue line corresponds to the auto-shading of the photovoltaic modules.

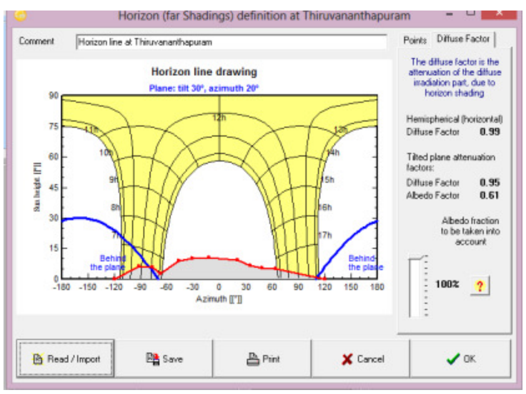


Figure 5. Insolation at location

(4) Near Shading : This part of the software simulates the effect of shadow from the near by objects which is less than 50 meters..

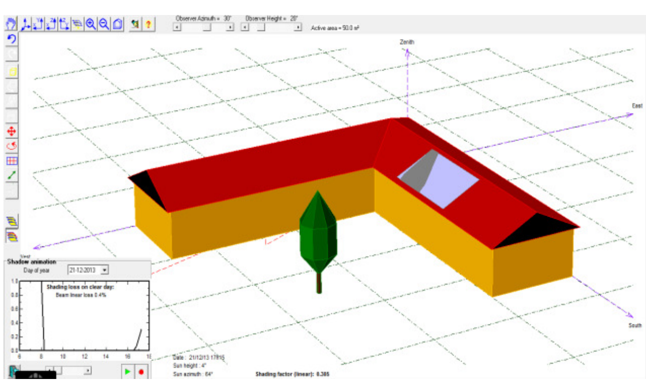


Figure 6. 3D simulation of effect of the shadow

For realization, a 3D simulation having a house and a tree with PV panels are drawn. The 3D construction requires architect's plans, i.e. exact knowing of sizes, positions and heights of the array and surrounding obstacles. The graph on the left of the visualization shows the shading losses on that particular instant along with the beam linear losses.

(5) Module Layout : The module layout has been used with the 3D representation of the field and its surroundings it would give a more realistic result and more details concerning the effect of shading on each string and the whole system.

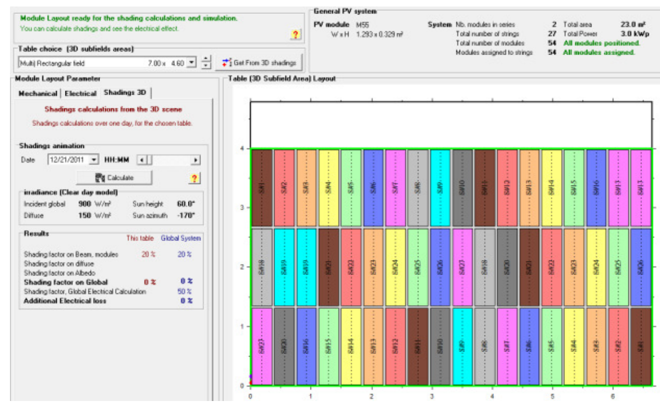


Figure 7. Module layout with shading

(6) System : Unlike from an on-grid PV system, the size of stand-alone PV system will depend on the demand of the user, where user needs to input the desired nominal power, or alternatively the available area for installing PV modules. In the off-grid PV system, inverter module needs to be chosen from the inverter database. All the strings of PV modules connected should be homogeneous means identical modules, same number of modules in series, same orientation etc. The figure below shows the schematic diagram of a stand-alone system. The diode shown here is the bypass diode used for the protection purpose.

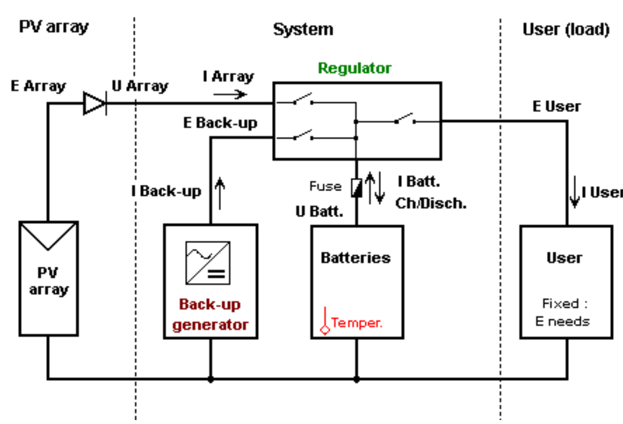
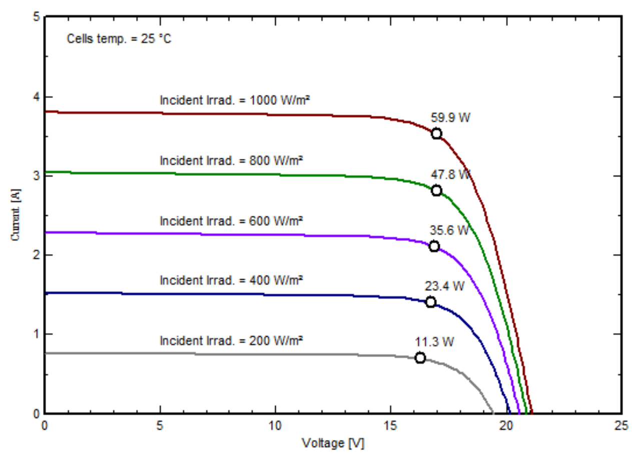


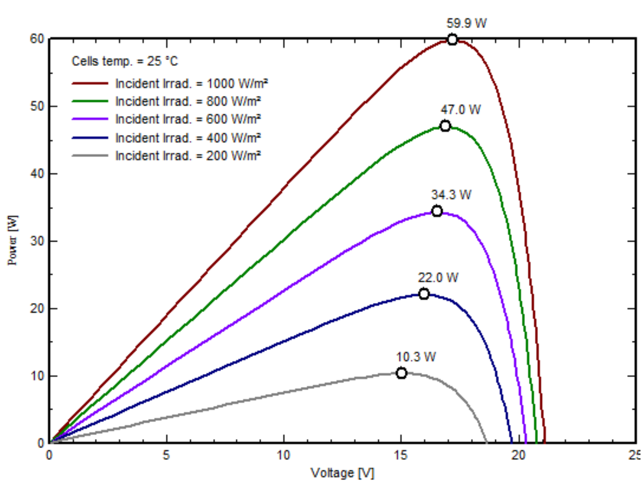
Figure 8. Schematic of the system

4. SIMULATION RESULTS

A. PV Modules : In order to understand the basic PV module and array characteristics, we use the I-V characteristics commonly found in manufacturing data sheets. PV module manufacturers use different solar cells; thus, it is expected that PV module characteristics are different from one manufacturer to another. Different qualities of solar cells are used by the same manufacturer for modules in market segments within the industry. In this section, current-voltage relationships of a single solar cell are expanded to a PV module and, finally, an array. There are numerous models for solar cell operation, but the five-parameter model is commonly adopted as it uses the current-voltage relationship for a single solar cell and only includes cells or modules in series[5][6].



(a)



(b)

Figure 9. (a)I-V and (b) P-V curves at various irradiance at 25^{0}C

B. Shading of PV Modules : The shading of a single photovoltaic cell results in the reduction of insolation by the fraction of the cell which is shaded and the current produced by the cell is reduced accordingly. When the shaded cell is in a circuit with bypass diodes and other PV cells in series and parallel combinations, the behaviour of the overall circuit becomes complex [5][6].

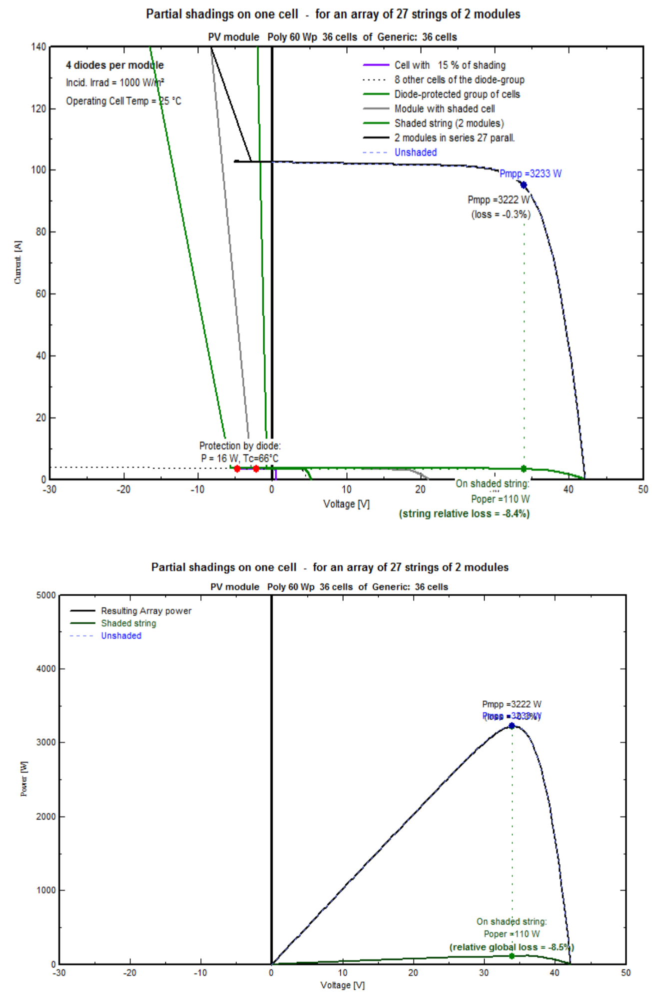


Figure 10. I-V and P-V curve under partial shading conditions

C. Shading factor analysis : The shading factor analysis gives the idea about how much of energy is loosing from the photovoltaic panels due to near shading as well far shading. Near shading means partial shading that affects a part of the panel. The shaded part changes during the day by day and also over a season. The shading factor is defined as the ratio between the energy generated from the illuminated part to the total area of the photovoltaic panel, or inversely, it is the loss of energy. The shading loss depend on the height of the sun as well as the azimuth for a near shading scene. The values in the table shown below represent the shading factor The value varies as per the season and time of the day. For example, 0.629 represents 62.9% of available irradiation over the panels during any particular time of the day.

Shading factor table (linear), for the beam component

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10°	0.033	0.000	0.000	Behind	Behind	Behind	Behind	0.000	0.000	0.000	0.000	0.000	0.063	0.088	0.000	0.000	0.000	0.019	0.033
2°	0.783	Behind	Behind	Behind	Behind	Behind	Behind	Behind	Behind	0.000	0.000	0.000	0.194	0.358	0.000	0.406	0.712	0.768	0.783

Shading factor for diffuse: 0.010 and for albedo: 0.266

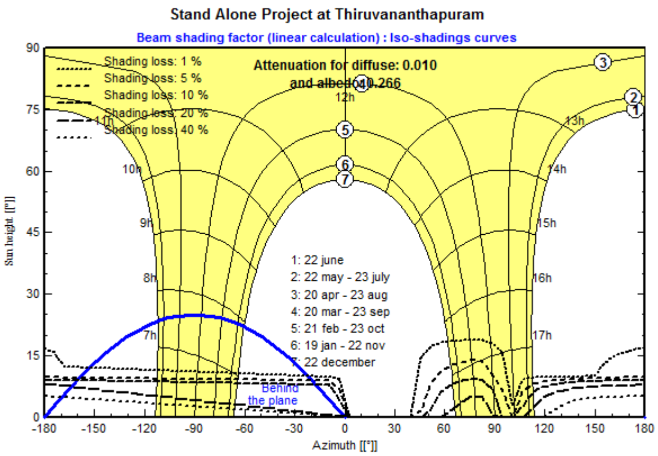


Figure 11. Shading factor table and shading scenes

D. Off-Grid System : The table below shows the annual balances and main results of on-grid PV system. From the table, it is seen that 27.31^{0}C is the ambient temperature over an year. The energy that can be delivered to the user is about 2.726MW.

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E User MWh	E Load MWh	SolFrac
January	175.5	159.6	0.931	0.440	0.232	0.232	1.000
February	172.4	157.5	0.921	0.438	0.209	0.209	1.000
March	202.7	185.7	1.089	0.513	0.231	0.232	0.999
April	182.2	165.3	0.963	0.452	0.224	0.224	1.001
May	170.1	149.6	0.830	0.387	0.231	0.232	1.000
June	137.0	121.7	0.694	0.309	0.224	0.224	0.987
July	158.6	142.2	0.836	0.371	0.232	0.232	1.001
August	169.5	151.4	0.874	0.394	0.232	0.232	1.000
September	171.5	153.7	0.903	0.428	0.224	0.224	1.001
October	166.1	149.2	0.843	0.399	0.232	0.232	1.000
November	144.6	133.3	0.756	0.334	0.224	0.224	1.000
December	160.7	148.1	0.863	0.395	0.231	0.232	1.000
Year	2011.0	1817.4	10.503	4.861	2.726	2.726	0.999

Legends: GlobHor Horizontal global irradiation; GlobEff Effective Global, corr. for IAM and shadings; E Avail Available Solar Energy; EUnused Unused energy (full battery) loss; E User Energy supplied to the user; E Load Energy need of the user (Load); SolFrac Solar fraction (EUsed / ELoad)

Figure 12. Balances and main results

There are different types of field losses that occurs in the grid-tied photovoltaic systems. The loss diagram of stand-alone solar photovoltaic system is as in fig.13.

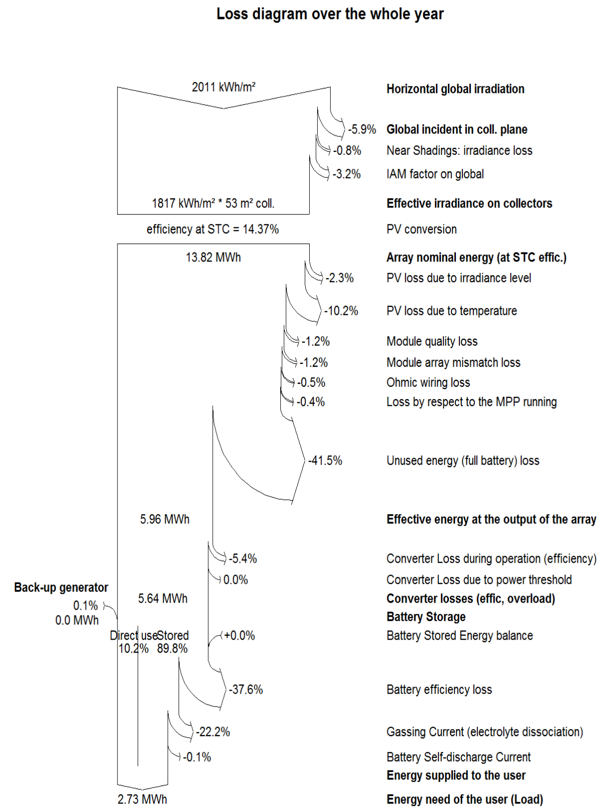


Figure 13. Loss diagram over an year

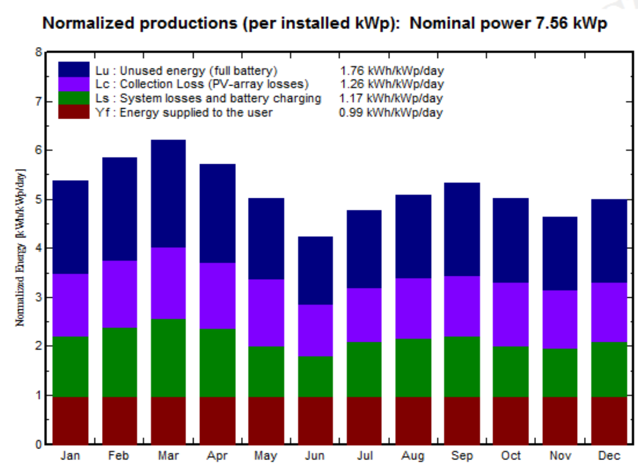


Figure 14. Monthly energy production with losses

5. CONCLUSION

The performance of the PV systems depend on material technology, production and manufacturing process. The losses in a PV system simulation may be determined by shadings, module behaviours etc. The PVsyst software provides a detailed analysis of all types of losses. PVsyst tries to use suited models for all parts of the PV system, including all identified sources of losses. The main uncertainties of the PV production remain: The meteo data (source, and annual variability) the PV module model, and the validity of the manufacturer's specifications.

6. ACKNOWLEDGMENT

First and foremost, I offer my gratitude to God Almighty for his blessings and deliverance throughout the preparation of this project.

I express my heartfelt gratitude to our Principal *Dr.M C Philipose*, Saintgits College of Engineering, for providing the facilities to present this project.

I take this opportunity to thank *Prof.Amey George*, Head of the Department, Electrical and Electronics Engineering for her support and encouragement in all my endeavours.

I am grateful to my project guide, *Dr.Jaimol Thomas*, Prof. EEE Department, for her whole hearted support and guidance in helping me present the project to the best of my ability.

I hereby extend my sincere gratitude to all the staff members of the Electrical and Electronics Engineering Department for all the support given to me.

Last, but not the least, I extend my sincere thanks to my parents and friends for their valuable help and encouragement in my endeavour.

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