Field Loss Accounted Design and Simulation of a Stand Alone Photovoltaic System

E. Suresh Kumar[1], Dr. Bijan Sarkar[2]

[1]Reserach Scholar, Production Engineering Department
Jadavpur University, Kolkata- 700 032. India
sureshconferencet@gmail.com

[2]Professor, Production Engineering Department
Jadavpur University, Kolkata- 700 032. India
bsarkar@production.jdvu.ac.in

Abstract

The performance of a photovoltaic system (PV) can be characterised by many parameters like latitude , ambient temperature, module temperature, long term degradation, irradiance , wind speed, wind direction, air gap between modules, dust, rainfall, corrosion, water vapour intrusion, humidity, mechanical load, salt mist, partial shading, summer-winter climate change, clearness of sky, ageing and component derating, panel orientation and shading, inverter sizing, accuracy of ratings, impact of actual operating conditions on equipment performance, equipment reliability and durability. The use of appropriate performance parameters facilitates the comparison of photovoltaic (PV) systems that may differ with respect to design, technology, or geographic location.Further electrical derating factors such as mismatch, component derating, wiring losses, circuit derating also causes reduced PV performance. The goal of a stand-alone system designer is to assure customer satisfaction by providing a well-designed, durable system with a 20+ year life expectancy. This depends on sound design, specification and procurement of quality components, good engineering and installation practices. This paper describes the design of a stand alone PV system for the geographic location, Kolkata in India, with field loss considerations and the simulation of the system using PVsyst, a software package for the study, sizing, simulation and data analysis of a complete PV systems.

Keywords: component derating, PVsyst, Depth of discharge, system loss flow chart.

I. INTRODUCTION

The factors potentially affecting the PV system performance are , geographic location (latitude, climate , fog cover, ambient temperature, wind), system design like panel orientation and shading, inverter sizing, mounting structure, equipment quality- accuracy of ratings, impact of actual operating conditions on equipment performance, equipment reliability and durability, Installation workmanship - system faults caused by improper installation, excess losses due to undersized wiring etc. A model developed based on field data may not be useful for a design engineer and reliability analyst to design and assess the performance of a PV system for some other climatic conditions in a different location[4],

which may in the same country or at a different continent. Performance varies with the environmental factors, viz, module temperature, ambient temperature, long term degradation, spectral issues, irradiance , wind speed, wind direction, air gap between modules, dust, rainfall, corrosion, water vapour intrusion, delamination of encapsulant materials, Thermal expansion, ultraviolet radiation, humidity, mechanical load, salt mist, partial shading, global climate change, summer-winter climate change, Clearness of sky, urban heat island (UHI) effect, ageing and component derating
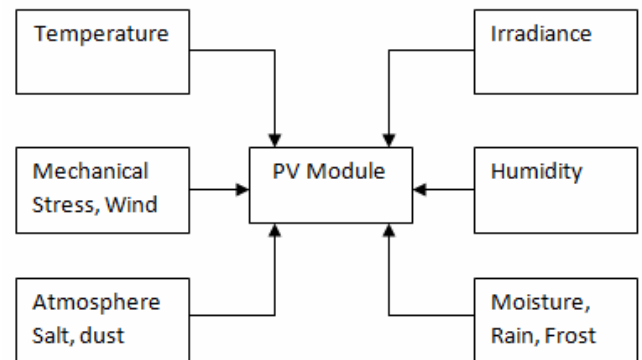

Figure 1: Various environmental stresses on PV module .

Further, the PV performance depends on material technology, production and manufacturing process.

The use of appropriate performance parameters facilitates the comparison of photovoltaic (PV) systems that may differ with respect to design, technology, or geographic location. The goal of a stand-alone system designer is to assure customer satisfaction by providing a well-designed, durable system with a 20+ year life expectancy. This design is for a stand alone PV system for the geographic location, Kolkata in India, with field loss considerations and the simulation of the system using PVsyst [4], a software package for the

IJCSMS International Journal of Computer Science and Management Studies, Vol. 12, Issue 01, January 2012
ISSN (Online): 2231-5268
www.ijcsms.com

19

study, sizing, simulation and data analysis of a complete PV systems[1].

II. PV PERFORMANCE FACTORS

The Factors affecting PV performance are summarized as follows. Temperature: Photovoltaic cell efficiency improves producing higher currents in cold temperatures. Voltage improves by 0.3 - 0.5% for every degree Celsius below 25° C. Seasonality: (hours of light per day) The near north of Ontario receives about 3.7 hours of sunlight per day. Winter average in our area is about 2 hours per day with the summer peaking during the longest days with an average of more than six hours per day. Weather: Even an hazy day will affect performance adversely. On an overcast day the solar module may generate as little as one tenth of its rated power. System Voltage: PV cells operate at a relatively stable voltage while the direct current (amps) they produce varies with light intensity. The current and power output of photovoltaic modules is approximately proportional to sunlight intensity.

III.   DESIGN PROCEDURE

Stand-alone PV system design procedure is as follows. Tare a few steps that need to be taken when designing a stand-alone system and the following steps are preferred.

(1). Determine the Load. Calculation of load can be down in two ways: either calculated on a daily basis or weekly. Regardless of which you choose you need to be as accurate as possible.
(2). Decide Battery Storage to be able to handle the load and allowing for additional days of battery storage, So the battery capacity requirement is as follows. Battery Storage is usually expressed in Amp hours. However, it can be given in Watt hours. For the load the battery storage (Ah) would be calculated as: Ampere rating x hours x additional days of back up power required in absence of solar irradiation.
(3). Determine solar radiation for the site location.
(4). Approximation of Array Size - If the system is going to be used all year round and the energy requirement is fairly constant then the design month will be December or January, that is when the weather is at its worst.

Array Size (Wp) = Daily energy requirement in Watt Hours [Wp] / Average Daily Peak Sun Hours in the design month / System Efficiency.

IV.   COMPONENTS OF PV SYSTEM

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

Charge Controllers : A charge controller is designed to protect the battery and ensure it has a long working life without impairing the system efficiency. Batteries should not be overcharged and the function of the charge controller is to ensure that the battery is not over charged. Charge controllers are designed to function as follows: Protect the battery from over-discharge, 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).

Batteries : The power requirements of stand alone PV systems are rarely in sync with the battery charging. Appliances and loads need to be powered when there is sufficient solar radiation, 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, environmental - will batteries be placed near water supplies etc.

Cables and Accessories : Cables need to be UV resistant and suitable for outdoor applications. It is very important to keep power losses and voltage drop in the cable to a minimum.

V. DESIGN AND SIMULATION

Design input data is as follows. Location : Kolkata(India), Plane : tilt = 30°, azimuth = 0°.
Required autonomy : 4 days, Loss of load : 5%, Battery/system voltage : 12V. Results : Array normal power : 563Wp, Battery capacity :770Ah, Energy cost : 1.96 EUR/kWh. (€ 1 =   69.8812).i.e., Rs.137/kWh.

Design steps for battery sizing required for PV system is given below.
1. Determine total watt-hours per day required from your load calculation.
2. Determine the number of days of storage (backup) required.
3. Multiply line 2 by line 1. (storage x watt-hours).
4. Determine depth of discharge (DOD) of the battery. 80% should be considered the maximum for deep cycle batteries.
5. Ensure that the batteries incorporate low temperatures by multiplying the answer in line 4 by the factors using the lowest expected weekly average temperature.

IJCSMS International Journal of Computer Science and Management Studies, Vol. 12, Issue 01, January 2012 20
ISSN (Online): 2231-5268
www.ijcsms.com

Shading of photovoltaic modules is one of the most significant causes of losses in a pv system[5]. In fact, the shading of 10% of the area of a system could cause a loss of 50%.

This disproportionate effect is caused by string design. If there is one shaded module in the string, the whole string underperforms. There are a number of technical solutions that involve inverters finding a new maximum power point
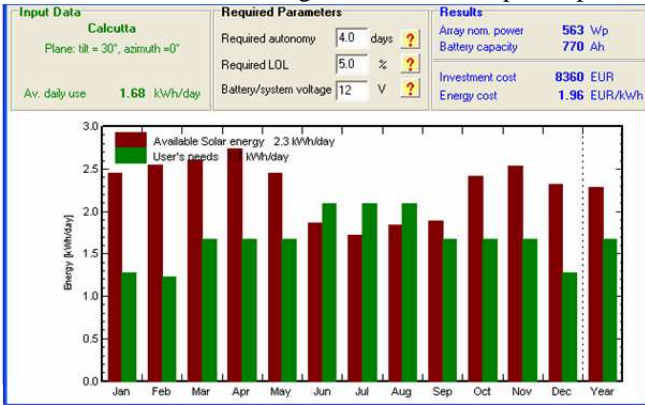
Figure 2 : Battery sizing requirement

or having one inverter per module. The best solution, however, is to avoid partial shading wherever possible. A shadow falling on a group of cells will reduce the total output by two mechanisms:1) by reducing the energy input to the cell, and 2) by increasing energy losses in the shaded cells. Problems become more serious when shaded cells get reverse biased. Figure 3 shows the effect of partial shading on one cell in a module.
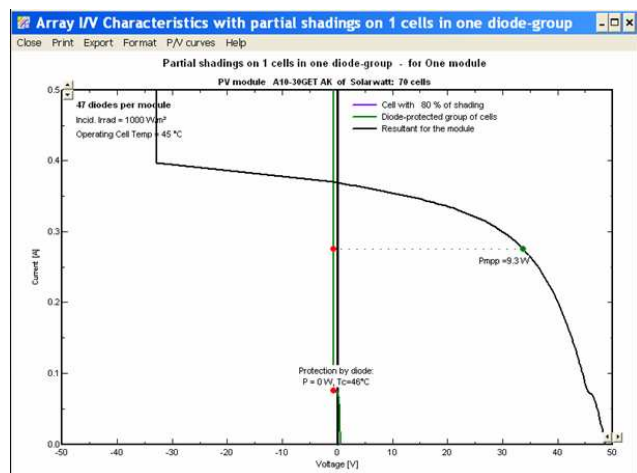

Figure 3 : Partial shading in 1 cell in one diode group for one module

Figure 4 gives the module solar watt resultant. Figure 5 shows the theoretical nature of I-V characteristics curve with and without bypass diode[6] and the simulated I-V characteristics is shown in figure 6. The effect of a bypass diode on an IV curve can be determined by first finding the

IV curve of a single solar cell with a bypass diode and then combining this curve with other solar cell IV curves. The bypass diode affects the solar cell only in reverse bias. If the reverse bias is greater than the knee voltage of the solar cell, then the diode turns on and conducts current. The combined IV curve is shown in the figure below.

Figure 7 shows the simulated block diagram of a stand alone PV system consisting PV array, battery and end user with
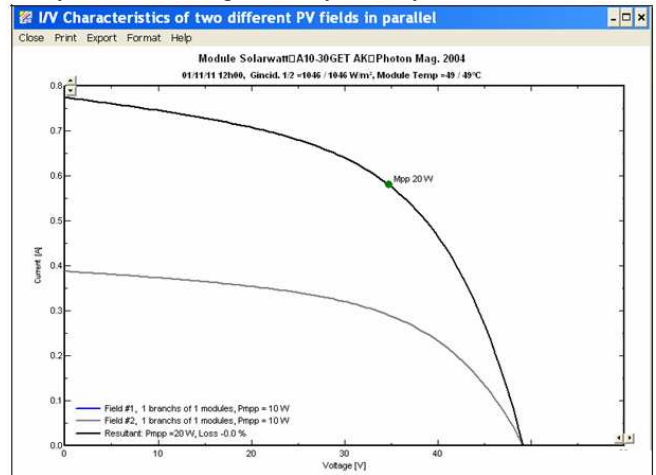

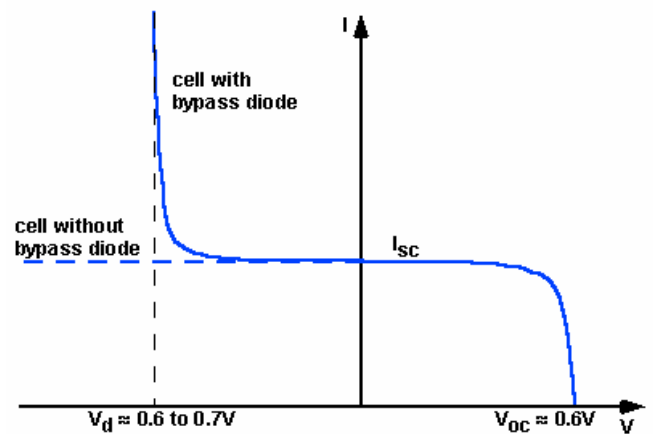Figure 4 : Module solar watt resultant as on 1st November 2011

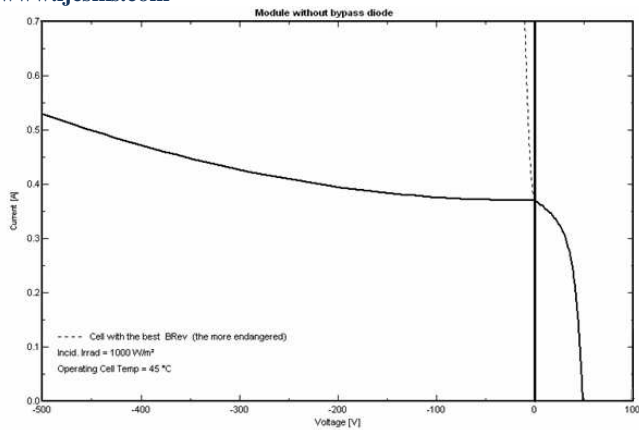Figure 5 : Module I-V characteristics with and without bypass diode.

IJCSMS International Journal of Computer Science and Management Studies, Vol. 12, Issue 01, January 2012
ISSN (Online): 2231-5268
www.ijcsms.com

21

Figure 6 : Module I-V characteristics without bypass diode (Simulated result)

relevant defined parameters. The simulation is with a standard back up generator of 1.5kW and the battery temperature is assumed to be constant and local temperature 20°C is taken into account. Figure 8 gives the simulated effective energy output versus global incident radiation for Kolkata based on generic meteo data for the PV module with nominal power of 0.26kWp, Maximum power point (MPP) voltage 36V and current of 0.3A.The open circuit voltage VOC must be calculated for the operating temperature (TC), for each cell it drops by about 2.3mV for each °C over 25°C.
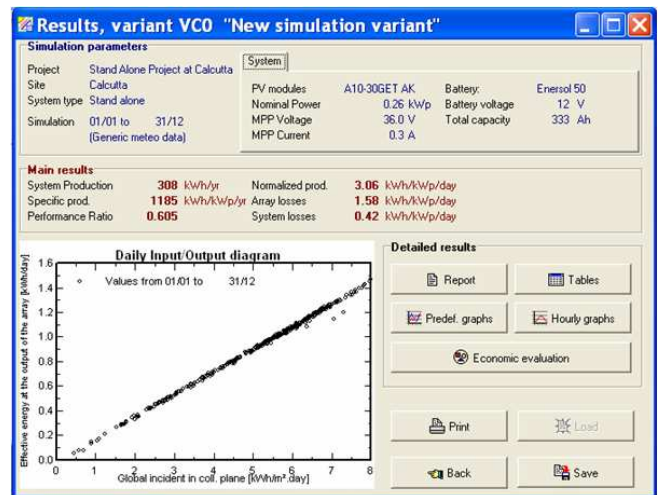

Figure 7 : Generated stand alone system with parameters.

Figure 8 : Daily input output diagram.

For a panel with *n* cells connected in series:

$$\frac{dV_{OC}}{dt} = \frac{V_{OC} - V_{OC}(25°)}{T_C - 25°}$$

The short circuit current ISC is directly proportional to irradiance (G). Therefore the short circuit current at the given irradiance Isc (G)) is given by:

I (G) I (at 1kW/m2) G (in kW/m2)

The cell temperature will normally be higher than the air temperature because they are black and sitting in the sun. The cell temperature under different conditions can be estimated using the *Normal Operating Cell Temperature* (NOCT), which is defined as the cell temperature under the following conditions: irradiance of 0.8kW/m2, spectral distribution AM1.5, ambient temperature 20°C and a wind speed < 1m/s.NOTC is normally in the region of 42 to 46°C. The following equation can be used to calculate the difference between the cell temperature TC and the ambient temperature TA (ambient temperature is the air temperature measured in the shade):

$$T_C - T_A = \frac{NOTC - 20}{0.8} \times G(\text{in kW/m}^2)$$

Figure 9 shows the simulation result of different irradiance parameters and ambient temperature per day as on 1st November, 2011.
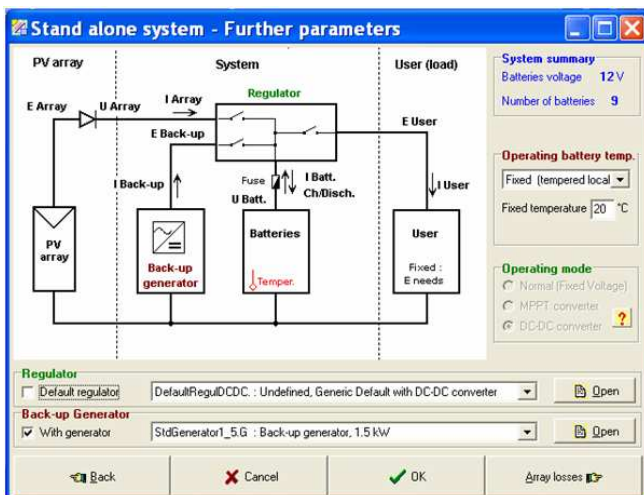
IJCSMS International Journal of Computer Science and Management Studies, Vol. 12, Issue 01, January 2012   **22**
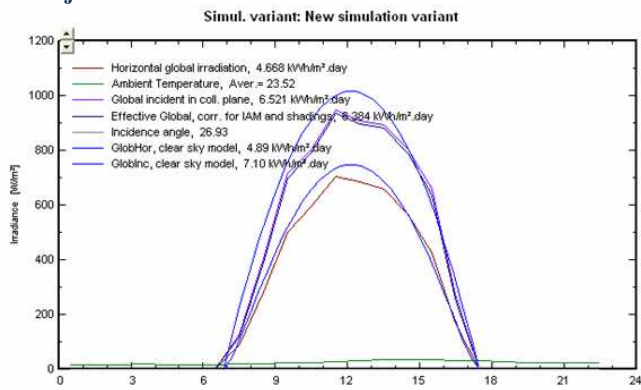**ISSN (Online): 2231-5268**
www.ijcsms.com

Figure 9 : Irradiance and ambient temperature variation as on 1st November, 2011.

Figure 10 shows the simulation result of array nominal energy at standard test conditions (STC), charge and discharge duration, normalized system production and PV loss due to temperature. Figure 11 shows the simulated PV system loss flow chart /loss diagram based on the environmental loss factors and system factors like losses due to temperature, module quality, mismatch , resistance change , loss in respect of maximum power point
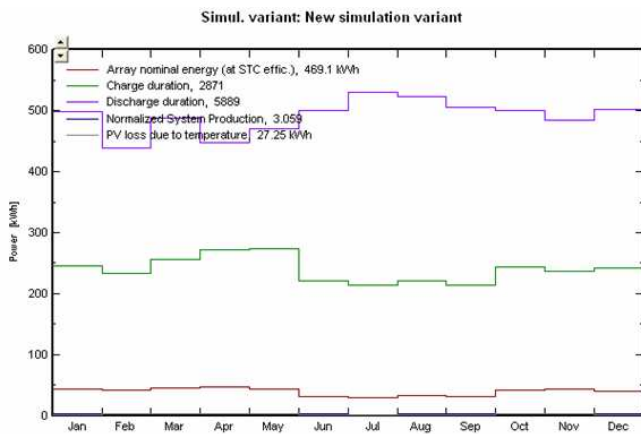

Figure 10 :Annual Power variations, charge – discharge durations .

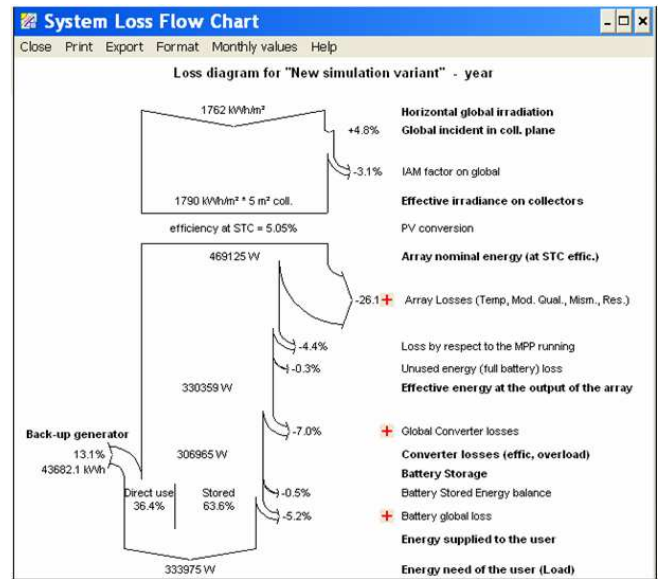(MPP) running, unused energy loss, global converter loss, battery global loss etc.

Figure 11 : PV System loss flow chart.

For the given design specification, the normalized power production and loss factors were shown as histograms in figure 12 with percentage of unused energy, PV array collection loss, system losses and battery charging per year (As on 2011). The histogram shows that the PV array collection loss is same during all seasons whereas varies during summer and rainy season. Figure 13 shows the performance ratio (PR) and solar fraction (SF) of PV system during the entire year . The term "performance ratio (PR)" refers to the relationship between actual yield and target yield. The PR of a photovoltaic system is the quotient of alternating current yield and the nominal yield of the generator's direct current.
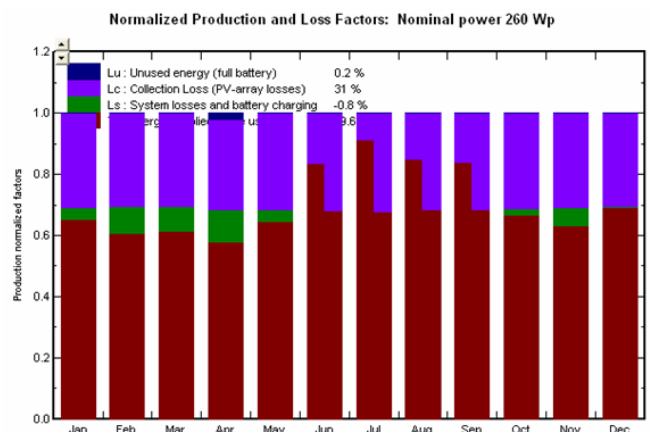

Figure 12 : Normalized production and loss factors

Solar fraction (SF) is the amount of energy provided by the solar technology divided by the total energy required. The

solar savings fraction thus is zero for no solar energy utilization, to 1.0 for all energy provided by solar. Figure 14
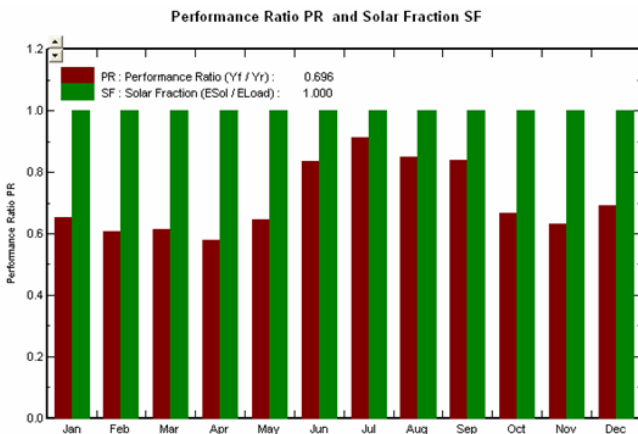

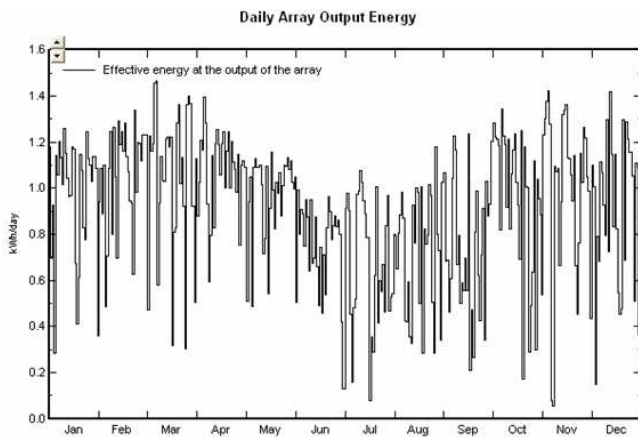Figure 13 : Performance ratio and solar fraction.

Figure 14 : Daily array output energy.

shows the simulation result of the effective energy at the output of the array.

VII. CONCLUSION

Losses in a PV system simulation may be determined by specific models(shadings), Interpretations of models (PV module behaviour),User's parameter specifications (soiling, wiring, etc). The PVsyst software provides a detailed analysis of all losses with each simulation. This is a valuable tool for checking the pertinence of the input parameters, comparing several simulation runs. PVsyst tries to use suited models for all parts of the PV system, including all identified sources of losses. It provides a detailed and quantified analysis of each loss giving a one-sight evaluation of the sizing and system-comparison tool. 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.

REFERENCES

[1] Mahendra Lalwani[1], D.P. Kothari[2], Mool Singh[1] (2010) , 1- Department of Electrical Engineering, MNIT, Jaipur, India, 2- Former Director i/c, Indian Institute of Technology, Delhi, India (2010) : Investigation of Solar Photovoltaic Simulation Softwares – International Journal of Applied Engineering Research , India, Volume 1, No 3, 2010.

[2] Performance of Solar Power Plants in India (2010) - , Submitted by Dr. .B D Sharma to Central Electricity Regulatory Commission , New Delhi, India.

[3] http://rredc.nrel.gov/solar/calculators/PVWATTS/version1

[4] http://www.pvsyst.com

[5] R. Ramaprabha (Member IEEE) , Dr.B.L.Mathur, SSN College of Engineering, Chennai, Tamilnadu, India (2009) : Impact of Partial Shading on Solar PV Module Containing Series Connected Cells, International Journal of Recent Trends in Engineering, Vol 2, No. 7.

[6] http://pveducation.org/pvcdrom/modules/bypass-diodes.

AUTHORS PROFILE

Dr. Bijan Sarkar is a Professor and the former Head of the Department of Production Engineering at the Jadvapur University, Kolkata. He is a specialist in reliability, terotechnology, tribology and operations management. He supervised many M.Tech and Ph.D thesis and published papers in many internationally reputed journals. He have contributions in many international conferences and a reviewer of many journals across the world.

E Suresh Kumar is an M.Tech holder in microelectronics from National Institute of Technology Karnataka, Surathkal, India. Currently he is a Research Scholar at Jadavpur University Kolkata and an Assistant Professor at College of Engineering, Trivandrum, India. His field of interest includes microelectronics, quality and reliability, renewable energy and photovoltaics.