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Design of Standalone Solar Power Plantusing System Advisor Model in Indian Context

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***Abstract:** The design parameters of standalone solar power plant should be analysed for feasible power generation and utilization at any site under consideration. Solar-powered photovoltaic system provides anunpolluted energy solution to current global warming. The solar input parameters and weather data are important to configure the desired power output. A simulation is necessary for the system which provides information on input data, loss under consideration, system efficiencies and gross energy yield. Standalone system is suited for small power generation setup which is not connected to grid. India being a tropical country with major sunny days throughout the year individual power plant setup helps consumers to depend less on government supplied power. Installation at site, system degradation and life time reliability analysis is crucial for long term power optimization.Virtual simulations have been carried out on PV systems for Bangalore station using system advisor model. This paper considers various design parameters to be considered before setting up a standalone system.*

***Index Terms:** standalone system, system advisor model, irradiation*

I. INTRODUCTION

This paper mainly discusses design and performance parameters involved to set up a solar plant for an educational institute. As most of utilization is during day time solar energy is suited for power generation and utilization. A geographical information system(GIS) helps in preliminary studies of site selectionand system sizing in developing the standalone system. For a normal day, Solar panels will receive at least 6hrs of irradiation expressed in kWh/m2/day. Most of Indian topography normally receives good sunshine throughout the year nearing to 300 days. Polysilicon is normally used even though it has less efficiency as it is of less cost compared to thin films and monocrystalline silicon. Polycrystalline silicon manufacturing process is simple and cost effective with less e-waste and is also the most widely used PV panels in India.

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The procedures outlined provide a method of predicting the long-term performance of PV array from data taken during field test and the data is available in few weather monitoring stations [1]. Solar PV system parameters are calculated located at Bangalore (12.9500 N, 77.6682E), India. Simulation has been carried out using System Advisor Model (SAM) [2] by National Renewable Energy Laboratory. The effectiveness and feasibility report of power management strategy is essential for further deployment [3]. Virtual simulation using system advisor model is performed which includes various losses, energy yields and efficiencies. The typical modelling steps of solar to electrical conversion at input side consists of modelling weather information, irradiance to the cell, cell temperature, shading and soiling[9]. The input irradiation and weather data is subjected to various losses shading and soiling thereby reducing the overall power generated. Module is desired to have ideal ambient temperature of 25^{o}C and 1000w/m^{2}. Also, electrical lossparameters such as wiring loss, inverter efficiency and conversion loss contributes to overall reduction in power generation.

A model validation should include the following:

1. Description of the PV system such as cell temperature, irradiance and cell material is being used for the validation.
2. Description of how the model performs for different parameter values.
3. Daily, weekly, monthly and annual statistics of model will provide details of power generated and load requirement.
4. Estimate of data losses and model uncertainties [4]

II. STANDALONE DESIGN

Photovoltaic cells are the basic elements of solar module. Modules can be connectedboth in series combination and parallel combination to achieve desired DC voltage. Many such PV modules are connected to form PV arrays which are of practical use.

The two types of installation are stand-alone system and grid connected system [5]. In this paper, a standalone system is considered for analysis where power generation is utilized without going to grid. PV systems face a variety of technical challenges such as physical mounting at the front end, batteries and inverters at back end, manufacturing defects along with high initial investment [6].

Table-I: Physical parameter requirement

Parameter	Value
Number of modules	5,544
Modules per string	12
Strings in parallel	462

Total module area	7,207.2m^2

Table 1 indicates the site design requirement to generate power for a small village community network, an apartment or an institution with around 6acres roof top with each module occupying an area of 1.3m^2.

III. DESCRIPTION OF SOLAR DATA AT BANGALORE

Selecting site location for solar plant installation is the primary step as it occupies considerable area for both rooftop and ground mounted. Solar irradiation which is the product of solar irradiance in Watts per square meter and time in hours determines the feasibility of installation at the desired site location. The total amount of radiation reaching the ground surface will get affected by some factors while entering the earth atmosphere resulting in attenuation caused by the following

a. Rayleigh scattering [7] due to small particles

b. Scattering by aerosols and dusts

c. Absorption in the atmosphere [8].

The different radiation entering earth's atmosphere cab aredirect, diffuse and reflected radiation after scattering and absorption [9]. If there is little or no scattering, radiation reaching the earth's surface is direct radiation. Else if scattering occurs due to atmospheric variations it is termed as diffuse radiation. Normally the radiation reflected from ground features is very less termed as reflected radiation.The global irradiance is determined considering these radiations.Fig 1 shows the simulated monthly irradiance data of different radiations. The ecliptic plane and equatorial planes due to difference in orbit along earth's tilted axis should be considered for maximization of received irradiance.

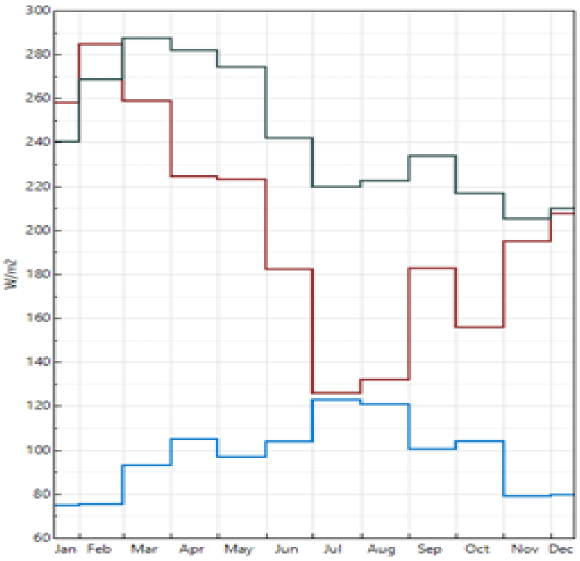

Fig. 1. Monthly average of different irradiance with Global (Maximum), direct beam and diffuses irradiance (minimum)

The hourly data of direct radiation Hb and diffuse radiation Hd is calculated based on global data radiation. Tilted surface global radiation Ht is normally measured using pyranometer and summation of these results in final daily irradiance.The data from weather simulation at Bangalore station considered for performance analysis is shown in table 2with 12 modules per string and 462 such strings which adds to 5544 modules. The datashown has considerable loss due to shading and soiling which in turn reduces DC electrical output. This can be reduced with proper alignment of panels and regular maintenance.The power management strategy is needed once annual irradiance and system power generated is known so as to optimally utilize it every day.

Table- II: Annual solar data of modules

Solar PV input data	Value
Irradiance total shading only kWh/yr	1.52E+07
Irradiance total shading+soiling kWh/yr	1.44E+07
Irradiance beam shading+soiling kWh/yr	8.56E+06
Irradiance beam nominal (kWh/yr)	9.01E+06
Annual GHI (Wh/m2/yr)	2.12E+06

IV. MODELING OF SOLAR PV CELL

The IEC-61853 Single Diode model predicts the performance of flat plate solar modules.Dobosetal has given a detailed description of the equivalent model.The solar cell equivalent model in fig 2 is used to calculate DC power output generated

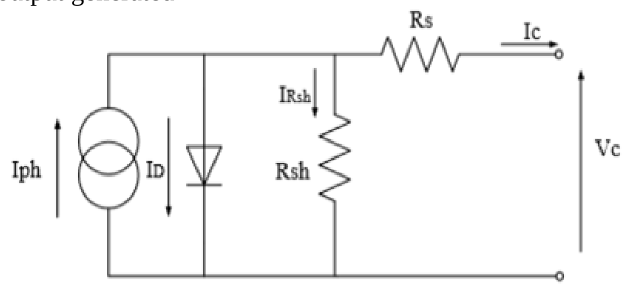

Fig. 2. Solar cell Equivalent circuit[9]

P(S) is Photovoltaic module output power,

f(S) is irradiance probability density function.

$$I_{Rsh}=I_{ph}-I_o(exp[\frac{V+IRs}{a}]-1)-\frac{V+IcRs}{Rsh}$$

The current voltage equation of a solar cell basically consists of five electrical parameters. They are diode non-ideality factor a, the light current I_{ph}, the reverse saturation current Io, the series resistance Rs, and the shunt resistance Rsh. The variation of series resistance is negligible. Other parameters can change depending on input data and the cell material technology. Typical values single cell model parameters are shown in table 3

Table-III: Solar PV CEC Model parameters

Solar PV CEC Model parameters	Value
The light current or input current	7.06231
Reverse Saturation or Output current Io	3.46E-10
Shunt Resistance: Rsh	42.4479
Series Resistance: Rs	0.377852
Ideality factor: a	1.56725
Capacity factor (%)	18.0292

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Modelling solar photovoltaic cell can be computed and average power generated by it is given by the equation shown below [10].

$$P_{avg} = \int P(S)\, f(S)$$

Capacity Factor CF estimates the performance of the PV module.

It is the ratio of average power output and rated power for the module Pmp. It is desired to have higher capacity factor for higher energy production. [11].

$$CF = \frac{Pavg}{Pmp}$$

The input light current isnearly linear with input solar irradiance. The single diode model is a straightforward method to characterize the current voltage (I-V) of a PV cell, and is widely studied in the work ([12], [13], [14]) and deployed in several commercial software models.

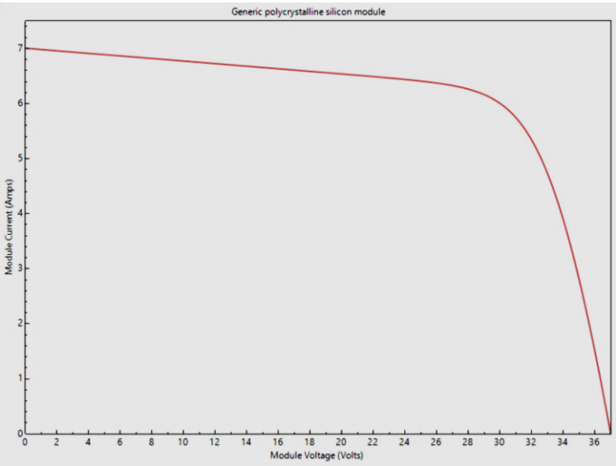

Fig.3. VI characteristics of a PV module

The VI curve shown in fig 3 haselectrical parameters like short circuit currentIsc, open-circuit voltageVoc, maximum power current and voltage and maximum power point which depend on the irradiance and temperature. Voltage variation is less with change in solar irradiance but light current changes more and is proportional to solar irradiance as shown in Fig 4. The maximum power is reached in the module when both Voc and Isc is high. This point can be a performance indicator for the module to work efficiently. Same modules are coupled in series which increases the voltage and retains the same current. Also in parallel connections current is increased retaining the same voltage. Using Identical modules reduces power loss between two devices.

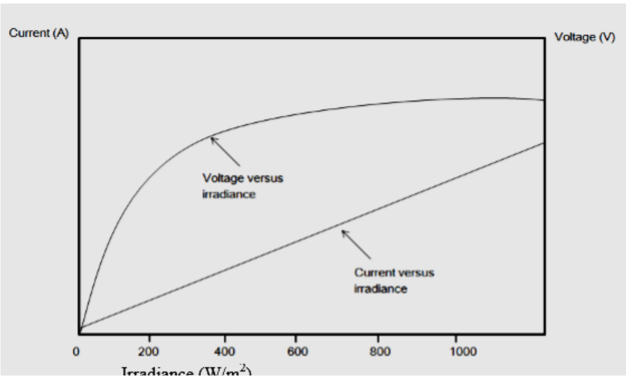

Fig. 4. Opencircuit voltageVocand short-circuit current Isc with variation in irradiance [15]

V. PV PERFORMANCE PARAMETER

Temperature - Temperature increase causes a fall in voltage but with a slight risein current. Therefore, as temperature increases output powerdecreases includingmodule efficiency. Material are also subjected to decrease in performance with higher temperature in the environment leading to damage of PV modules. Places like Bangalore will have an added advantage as there are no extreme weather conditions. Voltage current at different temperature on modules are shown in the fig 5 [16] [17] [18][19]

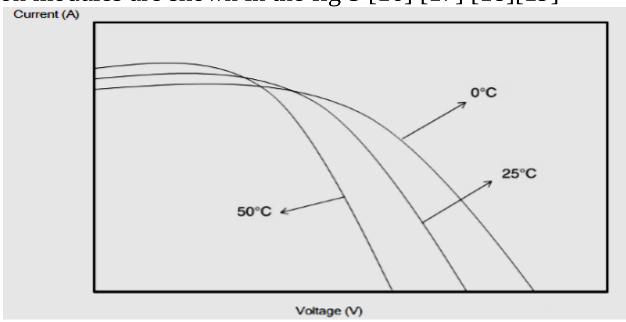

Fig.5. VI variation with temperature

Solar DC output-The maximum open circuit voltage is 37v per module which accounts to 444 volts for 12 strings as indicated in table 4. DC output depends on cell temperature and irradiance which is assumed uniform for each array.

Table- IV: Simulated DC parameters

String Voc	444.0v
String Vmp	360.0v
Total capacity kWdc	950.281
Maximum DC voltage	600.0v
System nameplate DC rating(kW)	997.92
Maximum DC output power	4,186.2W

Inverters- As inverter transforms direct current power to alternating current power it is used by AC load appliances. Inverter allows conditioning of power units tointegrate other components to form power conditioning unit (PCU) which acts as DC to DC converters and maximum power point trackers [9]. Inverters and batteries operate independently from PV array as stored DC is converted to AC in a standalone inverter system. But grid connected PV array inverters operate in parallels with utility grid. Table 5 shows performance parameters of standalone inverters.

Table- V: Simulated AC parameters

Number of inverters	227
Total capacity kWac	908
AC inverter efficiency loss (%)	4.54696
Maximum AC output power	4000Wac
Performance ratio	0.748992
Actual DC/AC ratio	1.10

Loss Parameters

Losses occur due to solar irradiance to DC power conversion and DC to AC conversion. The electrical wiring and connection losses due to aging or mismatch also contributes to overall reduction in power generation.

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Simulated data from table 6 using system advisor model shows different parameters that contribute to loss and objective should be to minimize it as much as possible.

Table- VI: Simulated loss parameters

AC wiring loss (%)	1
AC wiring loss (kWh)	15919.9

DC wiring loss (kWh)	34442.6
DC wiring loss (%)	1.97342
DC module modelled loss (%)	12.6921
DC diodes and connectionsloss(kWh)	8610.66
DC diodes and connections loss (%)	0.493356
POA soiling loss (%)	5.00001

VI. RESULTS AND DISCUSSION

The gross energy yield per year shown in table indicates the solar power generating capacity for a community or institution based network. The power conversion is around 10% of irradiance incident on the solar cell

Table- VII: Simulated energy parameters

Solar PV output data	Value
Annual AC energy gross (kWh/yr)	1.59E+06
Annual DC energy gross (kWh/yr)	1.75E+06

Monthly DC power generation shown in fig 6 power generation is less during the monsoon months. This is also a period where power demand is less as rainfall reduces dependency on ground water.

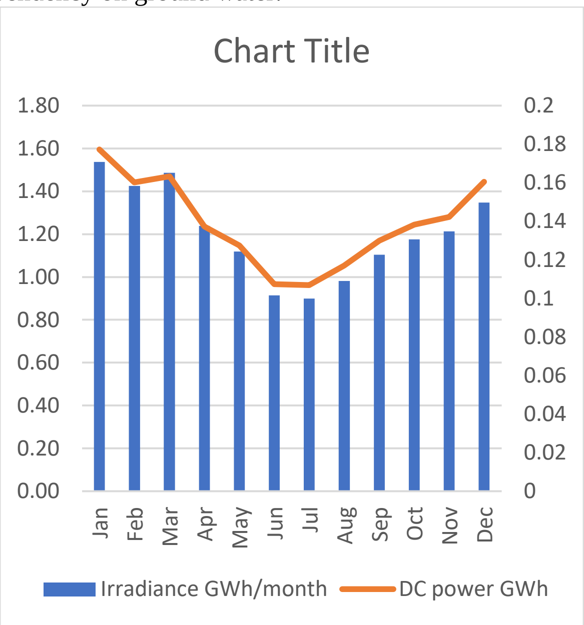

Fig.6. Monthly irradiance and Dc power graph

VII. CONCLUSION

Barring initial high investment, nonlinear weather Solar and area occupied by modules solar power has advantages for sustainable development and environmental protection. For a 6 acre, standalone plant setup which has 5544 modules each with $1.3m^2$ the gross AC energy yield for load utilization after considering practical losses is 1.59GWh/yr. This is sufficient for most of the villages of India for around 1000 families in present scenario. Power utilization near generation will drastically reduce Indian communities to reduce dependency on government. This study can be further carried out for other renewable sources in places where solar irradiance is less and develop a hybrid model to achieve self-sustainability.

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