Design of Standalone Solar Power Plant using System Advisor Model in Indian Context

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Abstract: The design parameters of standalone solar power plant should be analyzed for feasible power generation and utilization at any site under consideration. Solar-powered photovoltaic system provides unannulated 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. 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°C and 1000w/m². Also, electrical loss parameters 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 connected both 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          | 7,207.2m² |

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 1.3m².
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 are direct, 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)](image)

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 2 with 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]](image)

P(S) is Photovoltaic module output power, f(S) is irradiance probability density function.

\[ I_{Rs} = I_{ph} - I_{o}(\exp\left(\frac{V + IR_s}{a}\right) - 1) = \frac{V + IR_s}{R_{sh}} \]

The current voltage equation of a solar cell basically consists of five electrical parameters. They are diode non-ideality factor a, the light current Iph, 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   | 3.46E-10|
| Shunt Resistance: Rsh                  | 42.4479 |
| Series Resistance: Rs                  | 0.377852|
| Ideality factor: a                     | 1.56725 |
| Capacity factor (%)                    | 18.0292 |

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

\[ P_{avg} = |P(S) f(S)| \]
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].

\[
CF = \frac{P_{avg}}{P_{mp}}
\]

The input light current is nearly 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.

V. PV PERFORMANCE PARAMETER

Temperature - Temperature increase causes a fall in voltage but with a slight rise in current. Therefore, as temperature increases output power decreases including module 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 characteristics of a PV module

The VI curve shown in fig 3 have electrical parameters like short circuit current Isc, open-circuit voltage Voc, 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. Open circuit voltage Voc and short-circuit current Isc with variation in irradiance [15]

Table- IV: Simulated DC parameters

| Parameter                        | Value       |
|----------------------------------|-------------|
| 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 to integrate 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

| Parameter                        | Value       |
|----------------------------------|-------------|
| 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. Simulated data from table 6 using system advisor model shows different parameters that
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committee 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 connections loss(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 1.3m² 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.

REFERENCES

1. G. Barker Mountain Energy Partnership Longmont, Colorado P. Norton National Renewable Energy Laboratory presented at the Solar 2003 Conference; America’s Secure Energy Austin, Texas June 21–26, 2003
2. NREL GIS, Solar Maps. U.S. Solar resource maps, http://www.nrel.gov
3. Caisheng Wang, Senior Member, IEEE, and M. Hashem Nehrir, Senior Member, IEEE “Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System” IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 3, SEPTEMBER 2008 pg957-67
4. Joshua S. Stein, Christopher P. Cameron,Sandra National Laboratories, Ben Bourne SunPower Corporation, Adrienne Kimber First Solar, Jean Pospic BP Solar, and Terry Jester, Hudson Clean Energy, “A Standardized approach to PV System performance model Validation” Presented at 35th IEEE PVSC. Honolulu, HI June 25, 2010
5. E. Romero Cadaval and Q. C. Zhong, “Grid connected photovoltaic plants: An alternative energy source, replacing conventional sources” IEEE Ind. Electron. Mag., volume 9, no. 1, pp. 18–32, March 2015.
6. Bazilian,I.Onyeji,M.Liebrecht,I.MacGill,J,Chase,J.Shah,D.Glien, D. Arnt, D. Landfear, and S. Zhengrong, “Re-considering the economics of photovoltaic power,” Bloomberg New Energy Finance, 2012.
7. Stuart R. Wenham, Martin A. Green, Muriel E. Watt and Richard Corkish,—applied PHOTOVOLTAICS! Second edition, Earthscan, 2002
8. C. Honsberg, Solar Electric Systems, University of Delaware, ECE Sprin2008, http://www.cis.udel.edu/~honsberg/Elec620/02 Solar radiation .pdf Last access 4-1201
9. PV Performance modeling collaborative-PVPMC [details available online at http://pvpmc.org]
10. Bogdan S. Borowy, Ziyad M. Salameh, “Methodology for optimally sizing the combination of a battery bank and PV array in a Wind/PV hybrid system”, IEEE Transactions on Energy Conversion, vol. 11, No. 2, pp. 367-375, June 1996. (Article)
11. Ziad M. Salameh, Bogdan S. Borowy, Atia R.A. Arnin, “Photovoltaic Module-Site Matching Based on the capacity factor”, IEEE Transactions on Energy Conversions, Vol.10, No. 2, June 1995. (Article)
12. DeSoto, W; Klein, S.; Beckman, W “Improvement and Validation of a Model for Photo Voltaic Array Performance, Solar Energy”, volume 80, pp.7888.2006.
13. Boyd, M. Klein, S. Reindl, D. Dougherty, Evaluation and Validation of Equivalent Circuit Photo Voltaic Solar Cell Performance Models. I. Solar Energy Engr. Vol U33, 2011.
14. Dobos, A.: An Improved Coefficient Calculator for the California Energy Commission 6 Parameter Photo Voltaic Module Model. I. Solar Energy Engr., vol U34, 2012.
15. M. Cheggar et al. “Effect of illumination intensity on solar cells parameters Energy Procedia” 36 ( 2013 ) 722 – 729. Published by Elsevier
16. Bruno V L, Orioli A, Ciulla G, Gangi A D. “An improved five-parameter model for photovoltaic modules.Solar Energy Materials and Solar Cells”, 2010, 94(8): 1358-1370.
17. Mahmoud Y, Xiao W, Zeinelind H H. “A Simple Approach to Modeling and Simulation of Photovoltaic Modules”. IEEE Transactions on Sustainable Energy 2011, 3(1), page185-186.
18. Siddique H, Xu P, De Doncker R. Parameter extraction algorithm for one-diode model of PV panels based on datasheet values. 2013 International Conference on Clean Electrical Power (ICCEP), 2013.
19. Orioli A, Gangi A D. “A procedure to calculate the five-parameter model of crystalline silicon photovoltaic modules on the basis of the tabular performance data” Applied Energy 2013; 102): page1160–1177.

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