

Design Aspects of Standalone PV System with Two Simulation Tools



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Abstract: The conventional energy sources depleted day by date. Alternate energy requirement is necessitate for our daily life. Our energy demand is met by standalone PV based system. This paper explained the simulation of a standalone photovoltaic power system erected in Mailam with different simulation tools. Solar resources for the design of this system were taken from the National Aeronautics and Space Administration (NASA) Surface Meteorology at a location of 22° 59' S, 14° 29' E with annual average solar radiation of 5.14 kWh/m²/d. PV planner and PV syst simulation tools were used to analyze the design of photovoltaic power system model. The entire model was designed based on an hour-by-hour data depend on energy availability and its demands. A detailed design of standalone PV system with two different simulation tools were presented in this paper.

Index Terms: Stand alone PV system, PV SOL, PV syst, PV planner.

I. INTRODUCTION

Generally standalone systems are needed the places where people who could not get supply from grid. To Provide grid electricity to such remote areas are required higher costs to the supply provider. The easier way is to transmit power through stand-alone systems. This system can fulfill the requirements of domestic appliances. Power demand is satisfied by various non conventional energy sources. Any one of the non conventional energy sources is chosen depending upon the load profile and the local availability of the supply options and its installation cost. Most of the isolated areas are far away from the grid it have a high potential of non conventional energy sources like solar. Stand alone PV system set up for home includes a photovoltaic (PV) module, a rechargeable battery, a charge controller, and a inverters. The sizing of the system determines the “light hours” needed to operate each appliance of home. Simulation of energy sources is very

important to install any energy system. The main focus of work in this paper is to simulate standalone solar system with two different simulation tools, which will provide desired power to operate home appliances.

II. METHODOLOGY

For designing a good power system, one has to know the information where to install stand alone PV system. The following parameters such as current demand, load profile, intensity of solar radiation, installation cost of each component and its life usage time is important.

A. References of home system

From the available data, a profile of the home system was developed. This following profile shows the load variations and its electrical usage patterns with in the home.

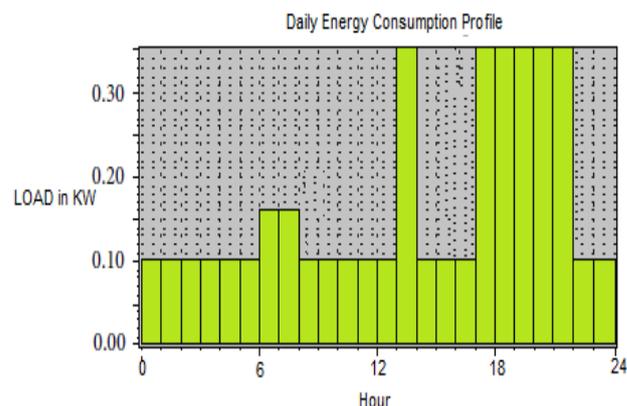


Fig 1 . Hour to hour of day profile and its electricity consumption in a home in Mailam (Tamil Nadu, India)

"Figure 1 shows the daily profile electricity consumption in a home in Mailam (Tamil Nadu, India) ". The homes in Mailam is are rural area and it is not require huge quantities of electrical energy for electrical appliances.

B. Pattern of Using of Electric Power within the Home

Table I: Estimation of every equipment’s energy usage in a single day

| Electrical appliances | Quantity | Load(power in Watts of one unit) | Total load power in watts) | Daily hours of actual utilization (hour.per day) |
|-----------------------|----------|----------------------------------|----------------------------|--|
| Television | 1 | 80 | 80 | 2 hrs |
| Fan | 3 | 20 | 60 | 6 hrs |

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| Bulb | 4 | 15 | 60 | 6 hrs |
|-----------------|---|-----|-----|----------|
| Refrigerator | 1 | 150 | 150 | 24 hrs |
| Washing machine | 1 | 250 | 250 | 1.30 hrs |

Table 1. shows an estimation of each equipment’s rated power. The lights are on in the homes of Mailam will always be from 6 am to 7 am By this time (6 am to 7 am) the home starts preparing for school. Majority of people leave from the home by 9 am and return back to home by 7 pm. Figure 2: shows the graphics of monthly solar radiation profile in Mailam. Day time [6 am–6 pm]. The lights are on at 6 pm to till 10 pm to do the daily work. At 10 pm, lights are off and they will go to bed, it is extended till 6am before the light comes in again. Day to date daily routines are washing clothes, watching TV, cooking etc.

C. Study Area

This paper focuses on the simulation study of photovoltaic power generation system for an home sited in Mailam located in Tamil Nadu. It is geographically located at 14.5995° N, 120.9842° E with annual average solar radiation of 5.14 kWh/m²/d. For simulation study, the solar PV technology was considered. In Mailam March is the hottest month of the year. During this month, the solar energy resource available is 5.14kWh/m²/d but in October it is about 3.0 kWh/m²/d [1]. The other month solar radiation is also taken into account while designing system sizing.

III. MODELING OF PV SYSTEM COMPONENTS

The general theoretical background is described below [2],[3], [4]

A .Model of PV system

The formula for calculating the output of the PV generator is $E_{PV} = y(t) \times A \times P \times \eta_{PV}$, (1) where $y(t)$ is the hourly irradiance in kWh/m² A is the surface area in m² P is the PV penetration level factor, and η_{PV} is the efficiency of PV generator.

B. Charge Controller

To Limit the battery from over charging a charge controller is used. Using this full charging of battery is identified, this decrease the amount of energy received from the energy source.

The model of the charge controller is presented below :

$$E_{OUTPUT}(t) = E_{INPUT}(t) \times \eta_{Charge\ Con} \tag{1}$$

$$E_{INPUT}(t) = E_{SUR-E}(t) \tag{2}$$

where $E_{OUTPUT}(t)$ is the hourly energy output from charge controller, kWh, $E_{INPUT}(t)$ is the energy input to charge controller, kWh, $\eta_{Charge\ Con}$ is the efficiency of a charge controller, and $E_{SUR-E}(t)$ is the amount of surplus energy from DC sources, kWh.

C. Model of Battery Bank.

SOC(State of charge) is the property of battery which is the cumulative sum of the daily charge/discharge transfers. The battery acts as energy source at the time of discharge , act as a load when charging. At any time t the state of the battery is calculated from the previous state of charge and energy production and consumption during the time from $t - 1$ to t . [2], [5]-[7]

$E_{BATTERY}(t) = E_{BATTERY}(t - 1) - E_{OUTPUT}(t) \times \eta_{CHARGING}$ where $E_{BATTERY}(t)$ is the energy stored in the battery at hour t , kWh, $E_{BATTERY}(t - 1)$ is the energy stored in the battery at hour $t - 1$, kWh, and $\eta_{CHARGING}$ is the battery charging efficiency. when the load demand is > than the energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at hour t can be expressed as [9] $E_{BATTERY}(t) = E_{BATTERY}(t - 1) - E_N(t)$ where $E_N(t)$ is the hourly load demand or energy needed at a particular period of time. The difference between minimum allowable SOC voltage limit and the maximum SOC voltage across the battery terminals is noted by "d". when battery is fully charged which is equal to $1 - DOD/100$. So, the depth of discharge (DOD) is as follows:

$$DOD = (1 - d) \times 100. \tag{3}$$

The maximum value of SOC is 1, and the minimum value of SOC measured in percentage is :

$$SOC_{Min} = 1 - DOD/ 100 \tag{4}$$

D. Modelling of Inverter

The output of PV panel is always Dc supply ,therefore an inverter is needed to connect electrical load to the PV panel. The inverter models for photovoltaic and battery bank are given below [8]:

$$E_{OUTPUT - INVERTER}(t) = E_{PV}(t) + \left(\frac{E_{BATTERY}(t-1) - E_L(t)}{\eta_{INV} + \eta_{DISCHG}} \right) \eta_{DISCHG} \tag{5}$$

where $E_{OUTPUT - INVERTER}(t)$ is the hourly energy output from inverter kWh, $E_{BATTERY}(t - 1)$ is the energy stored in the battery at hour $t - 1$, kWh, $E_L(t)$ is the hourly energy consumed by the load kWh, η_{INV} is the efficiency of inverter, and η_{DISCHG} is the battery discharging efficiency.

E. Generated power (P GE)in PV Model

Total power generated at any time t is given by [9],[10]

$$P(t) = \sum_1^{N_p} P_{PV} \tag{6}$$

where N_p are number of PV cells. Generated power P_{GE} will feed to the connected loads. when this $P_{GE} >$ load demand, then the E_{SUR-E} will be stored in the battery bank. The battery bank is to satisfy the constraint $SOC_{min} \leq SOC(t) \leq SOC_{max}$. The SOC_{min} is at 30%, while that of SOC_{max} is at 90%. This selected SOC minimizes the cost function.

F. Cost Function Model (Economic and Environmental Costs) of Energy Systems

The following equations helps to estimate the level of optimization of photovoltaic energy solution [8]

$$C_{annual,tot.sol+bat} = \sum_{s=1}^{N_s} (C_{acap,sol} + C_{arep,sol} + C_{aop,sol} + C_{emission}) + \sum_{b=1}^{N_b} (C_{acap,bat} + C_{arep,bat} + C_{aop,bat} + C_{emission}) \tag{7}$$

where $C_{acap,sol}$ is annual capital cost of solar power, $C_{arep,sol}$ is annual replacement cost of solar power, $C_{aop,sol}$ is annual operating cost of solar power, $C_{emission}$ is cost of emissions, $C_{acap,bat}$ is annual capital cost of batteries power, $C_{arep,bat}$ is annual replacement cost of batteries power, and $C_{aop,bat}$ is annual operating cost of batteries power.



Table II: Simulation results of production, consumption, losses, and excess (kWh/yr).

| Component | Quantity of Electricity(KWh/Yr) |
|----------------------------|---------------------------------|
| PV array generation | 2000 |
| Battery losses | 100 |
| Inverter losses | 200 |
| cable losses | 60 |
| Ac load utilization energy | 1400 |
| Excess energy | 250 |

G.Net Present Cost (NPC) for Energy Systems

The total net present cost (NPC) of a system is the present value is the all the component cost over its lifetime minus the present value of all the revenue during its lifetime. Revenues include grid sales revenue and salvage value. The net present cost (NPC) for each component is derived using [10,11]

$$C_{NPC} = \frac{C_{annual,tot}}{CRF(i,R_{proj})} \tag{8}$$

where the capital recovery factor is [12]

$$CRF = \frac{i \cdot (1+i)^N}{(1+i)^N - 1} \tag{9}$$

This method gives the economic optimization of standalone photo voltaic system.

IV. SIMULATION STUDY

The Simulation study is performed with two simulation tools such as PV sol and PV syst. The PV system with 5 MW installed capacity is located in Palaiyam, Mailam (22° 59' S, 14° 29' E). Based on the data availability and preliminary simulation value, the input parameters were adjusted according to it. In this simulation model, the size of the system is based on installed capacity. The system faced to south, i.e. azimuth angle is 0° or north, tilt angle should equal to latitude, i.e. 23°, inclination angle is 25° which gives 0 losses.

A. PV Planner Simulation

In PV Planner the user cannot see and adjust every step of simulation process. The input parameters are defined manually based on the parameters from PV syst simulation model, e.g. inverter’s efficiency and DC/AC losses. The standalone PV Planner simulation is shown in Fig.2. The new simulation variant is shown in Fig.3.

| | | | |
|--|------------------------|---------------------------------------|------------------------------------|
| Geographical Site | Madras | Country | India |
| Situation | Latitude 13.07° N | Longitude | 80.25° E |
| Time defined as | Legal Time | Time zone | UT+5.5 |
| | Altitude | | 10 m |
| | Albedo | | 0.20 |
| Meteo data: | mailam | NREL NSRDB Typ. Met. Year | Sunny_2000 to 2014 - TMY |
| Simulation variant : New simulation variant | | | |
| | Simulation date | 20/03/19 14h28 | |
| Simulation parameters | System type | No 3D scene defined, no shadings | |
| Collector Plane Orientation | Tilt | 25° | Azimuth 20° |
| Models used | Transposition | Perez | Diffuse Imported |
| Horizon | Free Horizon | | |
| Near Shadings | No Shadings | | |
| Storage | Kind | Self-consumption, No grid reinjection | |
| | Charging strategy | When excess solar power is available | |
| | Discharging strategy | As soon as power is needed | |
| User's needs : | Fixed constant load | 1000 W | Global 8760 kWh/Year |
| PV Array Characteristics | | | |
| PV module | Si-poly | Model | C88K-276P-A0 |
| Original PV/syst database | Manufacturer | Canadian Solar Inc. | |
| Nb. of optimizers | In series | 1 | In parallel 1 strings |
| Total number of PV modules | Nb. modules | 22 | Unit Nom. Power 275 Wp |
| Array global power | Nominal (STC) | 8.06 kWp | At operating cond. 5.48 kWp (50°C) |
| Array operating characteristics (50°C) | U mpp | 619 V | I mpp 8.9 A |
| Total area | Module area | 38.8 m² | Cell area 32.4 m² |
| Inverter | Model | 8E 10KTL-D8 | |
| Original PV/syst database | Manufacturer | Senergytec | |
| Characteristics | Operating Voltage | 160-850 V | Unit Nom. Power 10.00 kWac |
| | | | Max. power (±25°C) 11.00 kWac |
| Inverter pack | Nb. of inverters | 1 * MPPT 50 % | Total Power 5.0 kWac |
| | | | Pnom ratio 1.21 |
| Battery | Model | Open 12V / 100 Ah | |
| | Manufacturer | Generic | |
| Battery Pack Characteristics | Nb. of units | 2 In series | |
| | Voltage | 24 V | Nominal Capacity 100 Ah (C10) |
| | Discharging min. SOC | 20.0 % | Stored energy 1.9 kWh |
| | Temperature | Fixed (20°C) | |
| Battery Input charger | Model | Generic | |
| | Max. charging power | 0.1 kWdc | Max/ Euro efficiency 97.0/95.0 % |
| Battery to Grid Inverter | Model | Generic | |
| | Max. discharging power | 0.1 kWac | Max/ Euro efficiency 97.0/95.0 % |
| PV Array loss factors | | | |
| Thermal Loss factor | Uc (const) | 15.0 W/m²K | Uv (wind) 0.0 W/m²K / m/s |
| Wiring Ohmic Loss | Global array res. | 1163 mOhm | Loss Fraction 1.5 % at STC |

Fig 2: Grid connected design.

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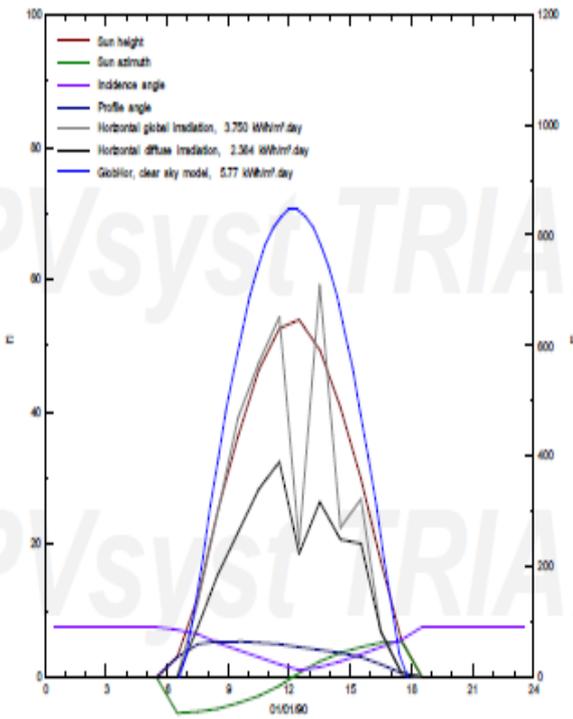


Fig.3. Simulation variant: New simulation variant

B. PVsyst 6.7.9 Simulation

PVsyst to be the most effective test tool for case study. To run simulation in PVsyst, series of steps to be performed with pre defined project location and their availability of solar data. The simulation is shown in fig.4

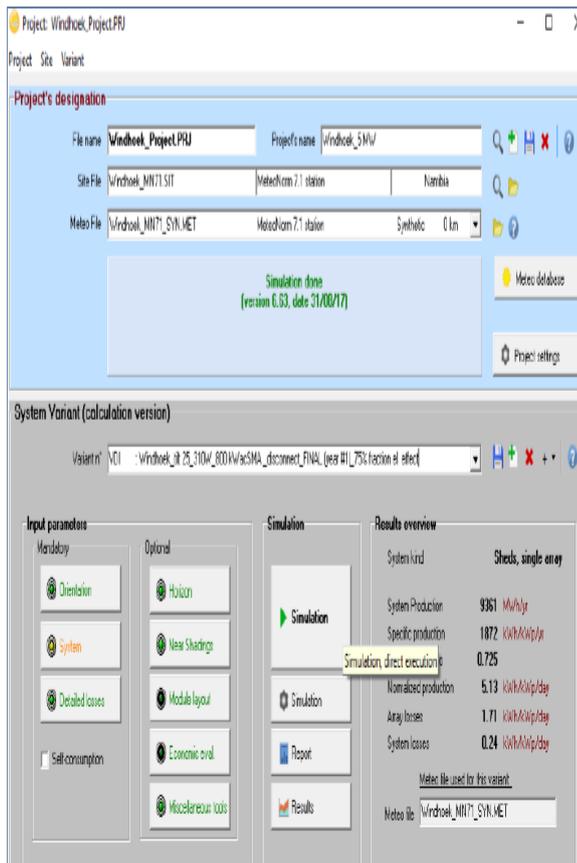


Fig.4. PV syst 6.7.9 Simulation

Orientation is fixed mounting system, tilt angle is 25° and azimuth angle is 0° , so that the loss by respect to optimum is to be 0.01 %. The number of modules to be taken as 18 which are connected in series. No of modules and its power, inverter power rating is chosen as the ratio of 1:2:1. Loss analysis includes the following : thermal parameters, resistance losses, aging factors, mismatch, module quality and LID degradation, soiling losses, efficiency of incidence angle and unavailability.

From measurements, thermal loss factor is based on a default value of $29 \text{ W/m}^2\cdot\text{k}$ for constant loss factor. Losses with external transformer is 0.1 % and ohmic losses is 1.0%. The efficiency loss is 2%. LID factor loss is 1.0 % which refers to degradation of crystalline silicon. Soiling loss of 2% was applied.

Far and near shading effect was performed based on the positioned 3D shading scene .The exact height of nearby obstacles was not calculated properly therefore the shading scene should be considered as an assumption. The shading scene is done in 2 steps such that linear shading and shadings according to the module strings. The shading according to the strings can be performed with electrical effect. The electrical effect assumed as 60-80%. Let as assume the fraction for electrical effect resulted is 75 % means 75 % of a string will be inactive if it is affected by shade. Here this is applied to simulation study.

C. Sizing of standalone system

| | | | |
|-------------------------------------|------------------------|-----------------|---------------|
| Geographical site | Palalyam | Country | India |
| Situation | Latitude 12.12° N | Longitude | 79.62° E |
| Time defined as | Legal Time | Time zone | UT+5.5 |
| | | Altitude | 47 m |
| Collector Plane Orientation | Tilt 24° | Azimuth | 18° |
| System pre-sizing evaluation | | | |
| Average use of energy | Daily 6.6 kWh/day | Yearly | 2423 kWh |
| Autonomy | 4.0 days | | |
| Loss-of-Load | Time fraction 4.9 % | Missing energy | 30 kWh |
| Battery system | Voltage 24 V | Capacity | 1302 Ah |
| PV array | Nominal power 1772 Wp | Nominal Current | 57 A |
| Economic gross evaluation | Investment 2541165 INR | Energy price | 69.61 INR/kWh |

Fig.5 Presizing of standalone system

Simulation of a PV system in desired location was performed in using PV planner. PV syst allows the user to import the data, models based on the solar data from PVSOL Premium and PV Planner were run in PV syst. The missing input data is wind speeds but it is required by PV syst simulation model. The pre sizing of standalone system is shown in Fig.5.

V. RESULTS AND DISCUSSION

The simulation is carried out based on synthesized data without actual measurements from the site, PVsyst produce more conservative simulation results for the system output. The PVSOL Premium simulation model was not produce good result due to lesser capacity.

The energy loss in PVsyst is less compare to PV planner and PV SOL. Simulation results from PVsyst with PVSOL data and with inbuilt data shows 9.49 GWh and 9.36 GWh of annual electricity production respectively. The difference is almost only 1.6%. The PVsyst solar data gives the lowest value of global in-plane radiation resulting in the most of the conservative output.



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VI. CONCLUSION

In the modern era the non-conventional energy system like standalove pv system is essential to met daily energy requirement in rural area.This paper mainly focusing on erecting solar power system in mailam area.The two different simulation tools such as PV planner and PV syst are used to analyze the design of photovoltaic power system model. The detailed design aspects of standalove PV system which is more appropriate is discussed so this paper is vert useful to the beginners to start solar project in rular area like mailam.

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