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SOLAR POWER - 1 KW SYSTEM ENERGY GENERATION STUDY AND COST CALCULATION

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ABSTRACT

Due to climate change and vulnerability of fossil fuels, environmental protection goals that lead towards a massive increase in renewable energy generation, e.g. photovoltaic (PV), solar thermal power, etc. have been proposed. Solar photovoltaic (PV) generation is one of the most important renewable energy resources, which is a green and clean energy too which is the need of the hour where we currently stand and see the Conventional energy Resources getting depleted at a very fast pace. The operation and control of the solar PV generation system are important for its application and a Case Study of 1kW system is presented in this paper along with the Cost Calculation and how this can relate to a Voltage support for the existing system.

KEYWORDS: Cost Calculation, Energy Generation Analysis, Solar, Voltage Support

INTRODUCTION

Energy Generation Analysis

The amount of electricity that one can generate from a solar panel depends on the size of your system, which way it is facing, whether there is any shading from trees or other buildings and the local climatic conditions.

In India (Considering Madhya Pradesh), a typical average generation is up to 3.7 kWh (calculated by the Energy formula given below) per day for a 1 kW system having 4 modules (250/220 Wp). In winter months the average daily generation is typically less than 3 kWh and in summer months it is typically greater than 5 kWh for a 1 kW system.

To estimate the electricity generated in output of a PV System

$$E = A * r * H * PR$$

E = Energy (**kWh**)

A = Total solar panel area (**m^2**) (1.663m X 0.998m)

r = Solar Panel Yield **(%)** (17 – 18%)

H = Annual average solar radiation on panels (Annual Average: **5.05** (kWh/m^2/day)

PR = Performance Ratio (Coeff. for losses; ranges between 0.5 to 0.9; standard generally taken as 0.75)

Example of Losses Details that Gives the PR Value (Depend On the Site, the Technology, and Sizing of the System)

- Inverter losses (4% to 15 %)

- Temperature losses (5 % to 18 %)
- DC cables losses (1 to 3%)
- AC cables losses (1 to 3%)
- Shadings 0 % to 80 %!!! (Specific to eacsite)
- Losses weak radiation 3 % to 7%
- Losses due to dust, snow (2%)
- Other Losses

The Specific Yield of a Plant Depends on

- The total annual irradiation falling on the collector/panel.
- The performance of the solar module, including sensitivity to high temperatures and low light levels.
- System losses including inverter downtime.

How Much a Battery Can Store?

Battery capacity can be measured in **Ah (Ampere - hour)**. We can convert this by multiplying Ah value by battery voltage.

E.g. 17 Ah, 12 V battery = 17 X 12 = 204 Wh

Solar Panel Efficiency

Solar panels typically convert between 8% and 18% of the available energy in sunlight to electrical energy. Crystalline panels have higher efficiency than amorphous panels but also cost more and their performance declines to a greater extent in high temperatures

- A 1 kilo Watt (kW) solar roof top you could generate 4.5 to 5 units of electricity per day.
- A 1 kW solar roof top could be set up in an area as small as just 100 square feet.

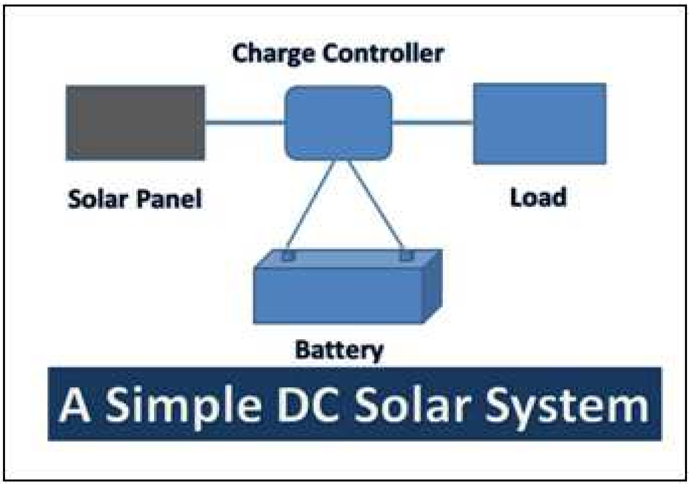
To put it in perspective, if you have ten 100 watt bulbs in your house and if you light them all for an hour, then you will be using one unit of electricity. In other words, if you use 1,000 Watts or 1 Kilowatt of power for 1 hour, then you consume 1 unit or 1 Kilowatt-Hour (kWh) of electricity.

Generally, a solar energy system will provide output for about 5 -6 hours per day. So, if you have a 1.0 kW system size and it produces for 6 hours a day, 365 days a year: This solar energy system will produce 2, 190 kWh in a year (1.0 kW x 6 hours x 365 days).

If the PV panels are shaded for part of the day, the output would be reduced in accordance to the shading percentage. For example, if the PV panels receive 5 hours of direct sun shine a day (versus the standard 6 hours), the panels are shaded 1 divided by 6 = 17% of the time (83% of assumed direct sun shine hours received). In this case, the output of a PV panel system would be 2190 kWh per year x 83% = 1818(approx) kWh per year.

To Calculate the Solar Power System We Have to Measure

- Solar Panel
- Charge Controller
- Battery
- Inverter (for AC output)



Now if a subscriber wants to setup a solar system for 2 bulbs and 1 fan. (12 volt DC)

(1 bulb=10 watt, 1 fan=20 watt) then the total load

2 bulb (10×2) = 20 watt

1 fan = 20 watt

Total = 40 watt

Now if he wants 4 hours back up time.

Then total load (4hour × 40watt) = 160 Wh^{-1} (watt per hour)

To measure the battery ampere for the above load.

Volt = 12

I =160/12 = 13.33 Ah

Battery is needed 12 volt, 14 Ah.

Now to Calculate the Solar Panel

Generally a battery charging current = 10% of its Ah

Charging current = 1.4 A (13.33/10 = 1.33 = 1.4)

Solar panel needed = 1.4 A 12 V

= 16.8 watt

So recommended the charge controller is 12 Volt, 1.4 Amp

Thus a solar system is calculated (System loss is not added with this measurement, so approximate 25% system loss will be added.)

So from calculation

- Solar panel =20 watt (20 watt is available)
- Battery = 12volt, 15AH (15AH, 20AH battery available)
- Charge controller = 12 volt, 2A (2A charge controller available)

The Overall Approach Adapted Will Be

First calculate the cost of each major component in terms of user specified variables. The major components are:

- Inverter
- Solar Panels
- Batteries

We will ignore adding in the cost of the charge controller, since this is only a few hundred dollars (whereas the whole system cost will be in the thousands of dollars).

The User Specified Variables will be

- Peak power required to power appliances
- Total energy produced/consumed per day
- Hours of sunshine (average)

Cost of Inverter as Function of Peak Power Required

Power is defined to be the rate at which energy is delivered (or captured), that is, energy per unit time:

$$\text{Power} = \text{Energy} / \text{Time}$$

For electrical applications, Power is usually specified in kilowatts (kW) which means in thousands of watts. There are two types of power requirements one needs to know when designing a solar system: The ***peak power delivered to the load***, and the ***peak power produced by the solar panels*** by the system.

The peak power delivered to the load is the total *maximum* power level one expects to be drawn by appliances in the home. For example, if one expects to run, *at most*, a 1 kilowatt hairdryer, five 100 watt light bulbs, and a 500 watt refrigerator, then the peak power would be:

$$P_{peak,\ usage} = 1\text{ kW} + 5 \times .1\text{ kW} + .5\text{ kW} = 2\text{ kilowatts}$$

Two kilowatts is a probably a good peak power target for small energy efficient solar home. Some people may require significantly more (say, up to 5 kilowatts).

The amount of peak power the system can deliver will be determined by the size of the system's inverter, the inverter being the device which converts the dc battery power to ac

$\mathbf{P_{peak,\ usage} = P_{peak,\ inverter}}$

For E.g. As if taken market prices for inverters, the costs of an inverter are about Rs 60 per watt, or (multiplying by 1000)

$\mathbf{Cost_{inverter} = 60{,}000/kilowatt}$

Thus, the cost of the inverter, as a function of the peak power used, is therefore:

$\mathbf{Cost_{inverter}\ (P_{peak,\ usage}) = P_{peak,\ usage}\ x\ Cost_{inverter}}$

Or

$$Cost_{inverter} = P_{peak,\ usage}\ x\ 60{,}000/kilowatt$$

Cost of Solar Panels as a Function of Energy Usage

The peak power produced by the solar panels is determined by the type and number of solar panels one uses:

$\mathbf{P_{peak\ panels}}$ **= Number of panels x power per panel**

Although the energy used by the appliances will of course be produced by the solar panels, it is not necessary that the peak output of the solar panels be equal the peak power used:

$\mathbf{P_{peak,\ usage}}$**: NOT NECESSARILY EQUAL TO:** $\mathbf{P_{peak\ panels}}$

This is because the power generated by the solar panels is stored up over time by batteries, so more peak power (but not energy!) can be delivered by the inverter than is produced by the panels.

Instead, we should calculate the peak power of the solar panels, and hence the number of solar panels, from the total amount of ***energy*** we want them to produce each day.

Calling the energy produced $\mathbf{E_{produced}}$, we want this to equal the amount of energy used each day,

$$\textbf{Important connection: } E_{produced} = E_{used}$$

We will specify energy in units of kilowatt-hours:

Energy = Power (in kilowatts) x Time (in hours) = Value of kilowatt-hours

Also, we need to know how long the sun shines each day on average. Let this be denoted by $\mathbf{T_{sun}}$,

$\mathbf{T_{sun}}$ = **Hours of Sunshine on average**

Using the formula for power and energy (Power = Energy / Time), we have

$\mathbf{P_{peak\ panels} = E_{used} / T_{sun}}$

Note that the fewer hours of sunshine available, the more peak power from the panels will be needed.

For E.g. As if we take it RS 400 to purchase and install a 1 watt panel. Therefore, the upfront cost of the solar panels *per watt* is

$\mathbf{Cost_{panels} = Rs\ 400/watt\ or\ 400{,}000/Kilo\ watt}$

Thus, as a function of Energy use, the cost of the solar panels will be

$\mathbf{Cost_{panels} = P_{peak\ panels}\ x\ Cost_{s.p.} = (E_{used} / T_{sun)}\ x\ Cost_{s.p.}}$

or

$$\mathbf{Cost_{panels} = (E_{used} / T_{sun})\ x\ Rs\ 400{,}000/kilo\text{-}watt}$$

Cost of Batteries as a Function of Energy Usage

The amount of energy stored (by batteries) determines how much energy can be used after dark, or on a rainy day. The number of kilowatt-hours we can store will be determined by the number and type of batteries we have:

$\mathbf{E_{stored} = Energy\ per\ battery\ x\ number\ of\ batteries}$

We will assume, in order not to discharge the battery more than 50%, that the batteries will be able to store twice the amount of energy we use:

$\mathbf{E_{stored} = 2\ x\ E_{used}}$

Again if we take the cost of batteries is about 5000 per kilowatt-hour of storage:

$\mathbf{Cost_{batteries} = Rs\ 5000/kilowatt\text{-}hour}$

The cost of batteries, therefore, *as a function of energy used*, is

$$\mathbf{Cost_{batteries} = 2\ x\ E_{used}\ x\ Rs\ 5000/kilowatt\text{-}hour}$$

Because we have included the factor of two, then we are probably safe to assume at least a six year lifetime on the batteries:

$$\mathbf{Lifetime_{batteries} = 6\ years}$$

Calculation of Upfront Cost

Adding up the costs of the inverter, panels and batteries, we find:

$$\mathbf{Cost_{upfront} = Cost_{inverter} + Cost_{panels} + Cost_{batteries}}$$
$$\mathbf{= P_{peak,\ usage}\ x\ 60{,}000/kilowatt + (E_{used} / T_{sun})\ x\ Rs\ 400{,}000/kilo\text{-}watt + 2\ x\ E_{used}\ x\ 5000/kWh}$$

Calculation of Life-Cycle Cost per Kilowatt-Hour

As mentioned above, today's solar panels are estimated to last ***at least*** 25 years. We will therefore use 25 years as our lifetime with which to calculate the life-cycle cost:

$\mathbf{T_{system} = 25\ years}$

Thus the total life-cycle cost per kilowatt hour is given by

$\mathbf{Cost_{kWh} = (Total\ Life\text{-}Cycle\ Cost)/\ (Total\ Kilowatt\text{-}Hours\ Used)}$

To calculate the total life-cycle cost, we need to account for periodic replacement of the batteries. Assuming a lifetime of six years for the batteries (which we helped insure by sizing the battery to twice the daily energy usage), the number of times we have to replace the batteries is

$$N_{batteries} = T_{system} / Lifetime_{batteries} = 25/6 = \text{(approximately) } 4$$

The total life-cycle cost of the batteries will therefore be

$$Cost_{batteries,\ life\text{-}cycle} = 4 \times Cost_{batteries} = 8 \times E_{used} \times 5000/kWh$$

The total life-cycle cost of the system will therefore be

$$Cost_{life\text{-}cycle} = Cost_{inverter} + Cost_{panels} + Cost_{batteries,\ life\text{-}cycle}$$
$$= P_{peak,\ usage} \times 60{,}000/kilowatt + (E_{used} / T_{sun}) \times Rs\ 400{,}000/kilo\text{-}watt + 8 \times E_{used} \times 5000/kWh$$

Because we defined the quantity E_{used} to be the number of kilo-watt hours used per day, the number of kilowatt-hours used over the lifetime of the system will be:

$$\text{Total kilowatt-hours used} = 25 \text{ years} \times 365 \text{ days} \times E_{used} = 9125 \times E_{used}.$$

We therefore have

$$Cost_{kWh} = Cost_{life\text{-}cycle} / (9125 \times E_{used})$$

Summary of Definitions and Formulas

$P_{peak,\ usage}$ = Peak power usage in kilowatts
E_{used} = Total daily energy usage in kilowatt-hours
T_{sun} = Hours of sunshine (average)
$Cost_{inverter} = P_{peak,\ usage} \times 60{,}000/kilowatt$
$Cost_{panels} = (E_{used} / T_{sun}) \times Rs\ 400{,}000/kilo\text{-}watt$
$Cost_{batteries} = 2 \times E_{used} \times 5000/kWh$
$Cost_{batteries,\ life\text{-}cycle} = 4 \times Cost_{batteries} = 8 \times E_{used} \times 5000/kWh$
$Cost_{upfront} = Cost_{inverter} + Cost_{panels} + Cost_{batteries}$
$Cost_{life\text{-}cycle} = Cost_{inverter} + Cost_{panels} + Cost_{batteries,\ life\text{-}cycle}$
$Cost_{kWh} = Cost_{life\text{-}cycle} / (9125 \times E_{used})$

PV Systems for Voltage Support

As already mentioned in the beginning of the paper, an increasing amount of renewable power generation is not rendering to the Peak load and abrupt demand from the consumers, but also enhances the voltage along the lines, which might lead to a voltage increase outside the allowed limits (typically +/- 10 % of rated voltage). This can be especially observed in lesser potential grids in the case of reversed power flow. A possible solution for that could be to use the installed PV systems for voltage support.

To investigate this issue and the voltage support possibilities a combination of PV System in with the electrical distribution grid can be considered. The biggest problems arise when the distribution lines are rather long and the PV systems very are too bulky. Depending on the overall amount of PV, voltage support of the PV systems can help to reduce the voltage problem. Moreover, a high reactive current is generated, which puts additional load on the existing cables and thus increases the losses on the lines.

The best results can be achieved when applying a well managed Q-control. But this would also end to high communication requirements, which are way too expensive from a cost-benefit angle. The second best control methodology can be the *power factor control* depending on the power generated. This is a simple and easy system to install and therefore till time the best solution.

CONCLUSIONS

The surplus of renewable energy sources is present and is scattered amongst various regions of India in both the rural as well as in the urban region. On the other hand, the coupling of nodes of different energy infrastructures is seen in more congested regions than in the less populated or scattered regions. The overloading of electric lines in a radially aligned grid rises with decreasing distance to the high voltage transfer points, due to the concurrency of renewable generation. Further on the region-based results will be scaled to the dimension of a nationwide area structure. Regarding the voltage support, best results can be seen in more developed infrastructures than in the less developed infrastructures and where PV systems do not solve the voltage issues, other measures such as hybrid storage have to be considered. With help of this paper the Case Study of 1kW system is presented in along with the Cost Calculation and how this can relate to a Voltage support for the existing system.

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