A study of design-based approach to solar energy as an alternative to grid-energy

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Abstract - *With reduction in global cost of solar panels, the world has seen rapid proliferation of solar energy during last couple of years. In a sunny country like India, it is one of the most efficient energy resources and hence it is attracting a lot of attention from both industries as well as research communities as switching to solar for energy fulfilment can help India in achieving both energy independence and zero-carbon future. In this paper, we have built a design model of harnessing solar energy with the use of solar panels and also maximizing our solar power productivity using autonomous solar tracking algorithms. We have also presented a detailed study of economic as well as some of the technological aspects of solar energy installation.*

Key Words: PV module, Kilowatt-peak, PGF, Payback time.

1. INTRODUCTION

Due to unsustainability as well as environmental concerns that are associated with harnessing energy from conventional carbon-origin sources, the world has seen exponential rise in both research and investment in renewable energy in recent decades [1]. For example, Costa Rica, a country in Central America has been running on 100% renewable sources since late-2016 [2]. Among renewable sources of energy, solar energy is becoming one of the major sources of renewable energy these days. Having blessed with 300 sunny days on average annually [3], India is on brink of a solar energy revolution thanks to latest efforts by energy-concerned authority. Our goal in this paper is to introduce a systematic model of solar panel installation by taking into account various economic as well as technological aspects involving in migrating a conventionally grid-powered habitat into grid-independent solar powered energy system. For this purpose, the authors of this paper have taken the hostel no. 10 of MANIT, Bhopal as a base for design-specific study. Also, in order to nullify the daily variances in solar power production, we have advocated usage of solar panels equipped with solar tracking algorithms.

2. LITERATURE REVIEW

2.1 Major system components

A solar PV system comprises of following sub-systems:

a) PV module:

Produces electrical energy from sunlight by photo-electric effect. They can be of many types—poly-crystalline, mono-crystalline, thin film solar modules etc [4]. We have selected mono-crystalline solar panels for our design as they are built from high grade silicon and hence is highest efficient and less space-consuming, though polycrystalline panels can also be used.

b) Solar charge controller:

It prevents battery overheating by regulating the amount of voltage and energy received by battery from panel. Thus, it also helps in battery life prolongation.

c) Solar tracker hardware and software:

In order to reduce daily variability of solar irradiance due to relative motion of the Sun with respect to earth, a solar tracker system is embedded in PV system in order to optimize power output which allows it to orient itself with respect to the sun all the time.

d) Battery system:

Stores energy to supply power to electrical appliances whenever necessary.

e) Load:

It is the electrical appliances that are connected to the PV system such as radio, TV, refrigerator, air conditioner etc.

f) Auxiliary energy sources:

They are diesel generator or other renewable energy source for making up the deficit energy whenever required.

2.2 Solar terminologies and factors

a) Kilowatt-peak:

Kilowatt peak stands for peak power. This value indicates the yield control accomplished by a solar module under full sunlight based radiation (under set Standard Test Conditions). Sun based radiation of 1,000 watts for each square meter is used to characterize standard conditions. The peak power is sometimes written as "P = 1 kW_p" as opposed to "P_{peak} = 1 kW". In the context of domestic PV installations, the kilowatt (kW) is the most common unit for peak power, sometimes stated as kW_p.

b) Solar tracking principle:

The sun tacking device solar panel consists of two LDRS, solar panel, stepper motor and ATMEGA16 micro controller. Two light dependent resistors are arranged on the edges of the solar panel light dependent resistors which produce low resistance when light falls on them. The stepper motor in the direction of the sun so that panel can be arranged in such a way that the light on two LDRs which have high intensity i.e. low resistance compared to the other. The stepper motor rotates the panel at certain angle. When the intensity of the light falling on the right LDR is more, panel slowly moves towards right and vice -versa. If the intensity of the light becomes constant, then there will be no rotation.

c) Panel generation factor(PGF):

Panel Generation factor signifies the maximum watt peak needed to meet the requirement of electricity from solar panels. PGF varies from location and climate, meaning thereby different locations might have different PGF depending upon the quality of solar insolation and irradiation falling on that place. There are empirical relations to arrive at the PGF. For India, it is around 4.32 [5].

2.3 Panel installation factors

In order to evaluate the feasibility of solar power installation in an area, following factors have to be considered-

a) Solar panel and temperature:

Efficiency of solar panels decreases with increase in ambient temperature. For each degree rise in temperature above 25˚C the panel output decays by about 0.25% for amorphous cells and about 0.4-0.5% for crystalline cells [6]. Hence, a same panel will produce higher energy output in winter than it does in summer. In Bhopal, average temperature is around 25˚C and hence it is ideal for solar energy generation, though during winter efficiency increases.

Also it has been observed that the efficiency of solar panels can be enhanced by an amount up to 60% by usage of focusing mirrors due to increase in solar energy irradiating the panels [7].

b) Amount of solar irradiance in the area:

The area must receive fair amount of sunlight during both summer and winter in order to achieve a sustainable solar solution.

Bhopal receives a fairly good amount solar irradiance amounting to 5.61 KW-hr/m^2/day. During summer it receives highest spike in solar irradiance with 7.20 KW-hr/m^2/day and during winter it dips down to around 4.36 KW-hr/m^2/day [8]. Hence, Bhopal is an ideal place for solar energy installation.

c) Shading free area:

Regardless of the possibility that a rooftop harnesses high amount of solar irradiance, sunlight based PV control plant needs to be placed in areas without shade zone. Shadows may originate from neighbouring structures like high altitude structures, cell phone towers, hoardings, trees. It might even originate from the PV plant itself – a line of boards may cast shadow on the lines behind it. Also it is noteworthy that at higher latitude places of earth, shadows are longer and extensive rooftop space is required for the plant. However, in case of India, it is a minor issue. Shadows not just decrease the panel yield, they may also eventually cause system failure. Shadowed areas turn from bring conductor to insulator which causes gradual heat up of the system and can eventually burn up those areas [9]. Such damages are not covered by warranty.

d) Tilt of solar panels:

Tilt angle is the angle the panel make with vertical axis. In order to maximize solar power generation, panels should face the direction of the irradiating sun. But there are a number of variables in figuring out the best direction. In the northern hemisphere, solar panels should face south while in southern hemisphere, it should face north.

Figure 1: Average values of tilt angle for panels during different seasons for Bhopal

e) Mounting location:

In case there is a substantial amount of waste land or unused area, panels can be mounted there if there is not a lot of area available in roofs. In our study, we have done calculations to find the mounting area needed for solar panels in roofs.

f) Cable thickness:

Cable thickness pays a major role in reducing the amount of lost energy in form of heat. For this purpose thicker cables can be used as it will drop down the resistance and as a result reduce voltage drop. Another solution is to use panels with higher rating. In order to maintain a nationwide uniformity in the quality of cables the Ministry of New and Renewable Energy (MNRE) in India specifies that cables adhere to IEC 60227 / IS 694 or IEC 60502 / IS 1554 (Part I & II) [10].

g) Charge Controller unit rating:

The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3.

Solar charge controller rating = Total short circuit current of PV array x 1.3 [11]

h) Energy storage(battery) efficiency:

Lead acid batteries are the most common choice for battery systems. Whenever backup is required batteries are needed for charge storage. All batteries discharge less than what go into them; the efficiency depends on the battery design and quality of construction; some are certainly more efficient than others.

If a battery is charged with constant charge current Ic for a time period ΔT_C,

Energy input to the battery, $E_{in} = I_C V_C \Delta T_C$

Similarly if discharged at current I_c for time ΔT_D,

Then, Energy output $E_{out} = I_D V_D \Delta T_D$

Battery efficiency = E_{out}/E_{in}

Also, in terms of specifications of these battery types in solar PV systems, deep cycle battery is preferred. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days.

i) Weight of the PV plant:

This is a critical factor in windy areas in light of the facts that solar panels along with their mountings can be fairly heavy. It is not a problem for concrete roofs but asbestos and other roofs may be too fragile and pose safety problems. So the roof composition should be sturdy enough to withstand the weight and wind load of the plant. After inspecting the roof of our study-place, we have designed the system suing 100watt mono-crystalline panels, which have an individual panel weight of 12.5 kg [4].

j) Inverter sizing:

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery.

For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. Generally, inverters are available with rating of 100, 200, 500 VA, etc.

For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation.

3. CASE STUDY AND DESIGN METHODOLOGIES

3.1 Energy consumption data

First step involved in designing of solar panel is to find out the consumption of total energy per day of all loads that need to be supplied by the Solar PV Systems.

Now, in this study, we have studied the energy requirement of the entire hostel by analysing the energy requirements for following segments of the hostel:

1. Hostel kitchen and dining hall
2. Bathroom
3. Corridor+ Leisure Room
4. Room electrical appliances

Next step is to calculate the energy to be supplied by solar panels. Here we have to take into account the loss factor that is associated with electrical circuits Multiply the total appliances Watt-hours per day times 1.3 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

Table -1: Power requirement of various sections of the habitat

S. no.	Sections of the habitat	Power required(W-hr/day)
1	Hostel Kitchen and dining hall	12701.30
2	Bathroom	1944

3	Corridor	9584
4	Room electric appliances	8365
5	Leisure room	285
Total energy Demand 32879.30 W-hr/day Or approximately 33 KW-hr/day		

So, total PV energy needed every day = 33 * 1.3 = 42.9 kW-hr/day.

3.2 Sizing and the number of solar panels required

Diverse size of PV modules will create distinctive measure of force. To calculate the power measuring of PV module, the peak watt (Wp) must be needed to calculate. (Wp) is used in solar life because of the changing mode of climate. So, Panel generation factor comes into role. This uses to take different values in different areas. The pinnacle watt (Wp) created relies on upon size of the PV module and atmosphere of site area.

Then, we divide the total Watt-hours per day needed from the PV modules (from total W-hr/day) by 4.32 to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.

After that, we divide the answer obtained in item 2.1 by the rated output Watt-peak of the PV modules available to. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

Hence,

Total Wp of PV panel capacity needed	= 42.9 kW-hr/day / 4.32
	≈ 9930.56 Wp
Number of PV panels of 100W needed	= 9930.56/ 100
	≈ 100 modules

So, power needed = 42.9 kW-hr/day.

3.3 Total area required for installment of Solar Panel

Mono-crystalline panel dimension = 1250*808 mm^2

= 1010000 mm^2

= 1.01 m^2

Total area for mono crystalline panel = 100*1.01= 101 m^2

Poly-crystalline panel dimension =1145*665 mm^2 = 0.76 m^2

Total area for poly crystalline panel = 100*0.76 = 76 m^2

Hence, we need 101 m^2 of total area for mono-crystalline for mono-crystalline and 76 m^2 of total area for poly-crystalline panel installation.

Total free space available in roof of the hostel = 2683.26 m^2

Hence, it is seen that amount of space required for panels is within the total spare area available in roof (Even if we allow moderate spacing between rows of panels). Hence, in terms of space availability, design is a feasible one.

3.4 Economic factors and payback period

In order to establish solar as a sustainable energy solution we have to calculate the economic parameters with it, we have calculated the total installment cost of solar modules for the total energy consumption of hostel no. 10 to compare it with the ordinary method without tracking mode and to determine the payback period.

It consisted of the cost of equipment used for the production of 43 kW of energy produced by solar panels. It has also included service cost, labor cost plus electrical peripheral cost.

1. Total installation cost = 550,000 Rs.
2. Service cost (including labor, supervision etc.) = 4000/KW Total Labor cost = 43*4000 /24 = 7,166.67 Rs.
3. Electrical peripheral cost

Electrical peripheral cost = 2000/KW

Total electrical peripheral cost = 2000*43/24

= 3,583.66 Rs.

Total cost for solar = (Total installation cost + Total Labor cost+ peripheral cost)

= 550,500 + 7,166.67+3,583.66

= 561,250 Rs.

3.5 Payback time calculation

Payback period is the length of time required for an investment to recover its initial outlay in terms of profits or savings. Lesser the payback time, greater is the economic yield of the system.

Now, average electricity cost in India = 6 Rs.

Payback time = (Total solar system cost/daily energy cost in habitat)

= 561,250/ (42.9*24*6)

= 90.85 day ≈ 3 months.

3. CONCLUSIONS

Our study of solar power based design approach has re-emphasized solar energy as a sustainable as well as an economically viable alternative energy approach. Though our study was conducted on an educational habitat, the same methodology can be extended for designing grid-less solar energy for other habitats, be it residential or office or industrial habitats. Also, once installed, solar energy incur very less maintenance costs, hence it is a long-term energy solution.With the future advancements in solar panel efficiency as well as more efficient storage systems, payback period will be dramatically enhanced, thus helping our society to achieve total energy autonomy as well as sustainable energy independence.

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