Rooftop PV Feasibility in Developing Cities in India – A Case Study

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Abstract— With global warming emerging as one of the biggest concern worldwide along with various environmental hazards and health issues, the need for green energy is becoming more and more prominent. Among various options of renewable energy the solar energy has maximum potential. If properly utilized it can solve our crisis of power demand. Also as the main input is free, so in long run it may also be very economical. In this paper an effort has been made to study and analyse the potential of a developing city in West Bengal.

Key words: Roof Top PV, Solar Irradiation, Web-GIS, Levelled Cost, Estimation

I. Introduction

As we all know that for power generation fossil fuel plays the pivotal role. If we keep aside the question of availability of natural fuels i.e. oil & natural gas in long run, then also the other issues which are of great concern – mainly issues like global warming, environmental hazards, health problems etc. can't be ignored. The primary cause of global warming is the emission of greenhouse gases. The average temperature may increase upto 50C provided carbon di-oxide concentration doubles in 40 years. Coal contains about 80% more carbon per unit of energy than gas does, and oil contains about 40 percent more [1]. If we think about global warming, it is giving huge impact in form of overall increase of earth temperature and enhancement in sea level. Apart from global warming the next big drawback is pollution of air – hydrocarbons and sulphur oxides produced by combustion of fossil fuels to generate electricity are the main pollutants. Considering the financial aspect, costs of fossil fuels are increasing day by day which in turn is making the electricity a more costly affair. Water and land pollution due to conventional power plants are also a big concern in recent times. Coal contains pyrite (a sulphur compound); so coal mines also contribute significantly in water pollution. These are the points where renewable energy in general and solar energy in particular takes the upper hand. PV cells generate electricity in such a way where the above mentioned disadvantages can be overcome. That's why we call it green energy. Solar energy is clean, reliable and green energy. PV cells when interconnected together (in series or parallel) are called a module. The module is flexible i.e. they can be designed according to our needs. PV systems can be widely categorised into two – grid-tied system (connected to electric grid) and stand-alone system (isolated system, not connected to grid). In grid connected system the solar PV system reduces the financial burden of the customer by drawing less amount of power from the service provider by utilising the power generated from the PV system and when excess amount of power is generated by PV system, then surplus power is pumped back into the grid. But there is one drawback of this system – in case of power outage, PV system will not be able to operate if there is no battery backup. Standalone systems are off-grid. They are supposed to meet the demand of the consumer where it has been installed. Generally demands are high at evening or night; so this type system is expected to have a battery backup (to store energy for night) or alternate source of energy like diesel generator or both.

As it is eminent that PV systems are a good option to supplement conventional sources of energy, so we concentrate now on the implementation and use of it. Now-a-days a lot of work is going on roof top PV systems..

II. Why Roof Top PV?

Roof top PV is having certain advantages:

- If we want to set up a PV system on large scale, a huge requirement of land is obvious. If we opt for roof top PV then it reduces the land requirement on national level to add more solar capacities.
- From consumer point of view it is advantageous as dependency on grid power reduces. It also helps not to depend too much on diesel generator. Above all it is a long term reliable source of power as we are using solar energy.
- Transmission & distribution losses are reduced to a great extent as power is to be consumed at the generating place.
- If designed wisely then commercial consumers can also take the maximum benefit of this by judicious use.

III. Basics of Rooftop PV

As we need AC for the appliances of our daily use and solar modules generate DC, so an inverter is inevitably needed to convert DC to AC. PV systems are specified by their rated outputs i.e. the maximum power produced if the panel is exposed to the solar radiation of 1000 watts per sq. Meter at a temperature of 250C. It is expressed as Wp i.e. Watt peak e.g. 300 Wp. This capacity increases at temperatures below 250C and reduces above 250C. Roof top PV systems are suitable for small scale generation rather than large scale generation. A solar module made by a number of basic PV cells is designed to give output of 10W to 300W. Depending upon the requirement these modules are connected in an array to give more output. Efficiency of PV module depends upon the materials used to build a solar cell. The amount of sunlight converted into electricity is termed as efficiency of solar cell. Roof top PV systems on residential buildings can have a rating of 5 – 20 kW. Table -I gives an idea of the requirement of roof area needed for systems with different outputs & efficiencies.

PV Module Efficiency (%)	**PV Capacity Rating (Watts)**						
	100	**250**	**500**	**1,000**	**2,000**	**4,000**	**10,000**
4	30	75	15	300	600	1,200	3,000

			0				
8	15	38	75	150	300	600	1,500
12	10	25	50	100	200	400	1,000
16	8	20	40	80	160	320	800

Table 1: Roof Area Needed in Sq. Ft

A. Components of a Roof Top PV system

A typical rooftop PV system has following components[3]:

1) PV Panel to convert solar energy into electrical energy. Although two types of modules are available but crystalline panels are preferred over thin-film modules mainly due to their efficiency and less requirement of space.
2) Batteries for storage purpose.
3) Inverter to convert DC power from the solar panel and battery to AC power
4) Connecting wires.
5) Rooftop: Typical weight of solar panel with structure is 15Kg per Sq. meter. The rooftop must be able to withstand this load.

Battery and inverter plays the key roles to decide the overall efficiency of the system. Therefore choosing the components correctly decides the use of solar system effectively.

Deep cycle batteries are always better option while choosing. They have long life (varying from 5 to 10 years) and so can provide electricity for long with around 80% efficiency. For better performance batteries should be kept in a well-ventilated space and should not be exposed to extreme climatic conditions.

While choosing inverter it must be taken care of that they are pure sine wave inverters with at least 90% efficiency. Modified sine wave inverters although cheaper but are not preferred due to the fact that they are heated up when in use and also give buzzing sound with appliances.

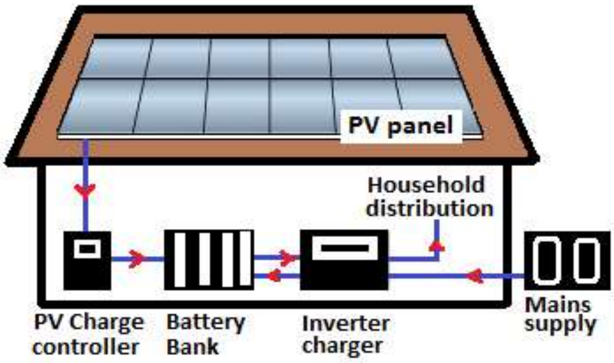

Fig. 1: Rooftop PV system

IV. ASSESSMENT OF SOLAR RESOURCE

To know about the solar resource available in a particular location we can take the help of solar energy map. This map will give us an idea about the availability of horizontal radiation (also termed as global horizontal irradiance or global horizontal irradiation). From this we can have an approximate measurement of the solar radiation reaching earth's surface.

A. Solar System Output

The output of a solar panel depends on the panel efficiency and availability of sunlight in a location. The factor that defines this output is called CUF (or Capacity Utility Factor). For India, it is typically taken as 19% and the calculation of units goes as:
Units Generated Annually (in Kwh) = System Size in Kw * CUF * 365 * 24

So typically a 1kW capacity solar system will generate 1600-1700 kWH of electricity per year (please note that this is just a thumb rule as the CUF will vary in different cities in India). [2]

B. Sizing of PV system

The area available at roof top primarily determines the size of PV system to be installed [2].

This can be estimated as follows:

Considering 70% of rooftop area can be used for panel's installation.

Size of solar system = Panel's rated output*(Rooftop area / each panel area)*70%

As a thumb rule, 10 Sq meter area is required for 1 kW capacity solar system:

C. How much installed capacity could fit on the roof?

An estimate of the potential installed capacity of the solar PV rooftop system CR, in peak kilowatts (kWp), may be made using the following equation:

$$C_R = \left(\frac{C_M}{1000}\right) \times \left(\frac{RCR \times A_R}{A_M}\right)$$

Where,
C_M = the rated capacity of individual module (Wp)
A_R = available rooftop area for installing solar modules (m^2) i.e. the total area minus any obstacles on the roof.
A_M = area of each module in (m^2)
RCR = roof cover ratio, which is the fraction of roof area to be covered by solar module

A typical value for the roof cover ratio (RCR) is around 0.85, which would allow for 15% of the roof to be free for spacing between modules and away from obstructions

D. Estimation Of Energy Delivery Capacity:

Energy yield (E) in kilowatt-hour can be estimated using the following equation:

$$E = C_R \times GHI_a \times D$$

Where,
CR = potential installed capacity of the solar PV rooftop system.
GHI_a = global horizontal irradiation over a 1-year period in kWh/m^2. Values can be obtained from a national or regional solar map.
D = derate factor for converting direct current (DC) to alternating current (AC). The derate factor generally ranges between 0.6 and 0.8 (Honda et al. 2012). A typical derate factor of 0.75 can be used.

A typical classification for determining suitability of solar irradiation for PV system is listed in Table – II.

	Limited suitability	Suitable	Highly suitable	Excellent
Photovoltaic (PV)	below 1000 kWh/ m^2	1000–1500	1500–2500	2500–3000 kWh/m^2/year

	/year (GHI)	kWh/ m^2 /year (GHI)	kWh/ m^2 /year (GHI)	(GHI)

Table 2: Suitability Classes Of Solar Irradiation For Pv System

V. SOLAR RESOURCE AVAILABLE AT THE TARGET SITE

To find out the solar photovoltaic generation potential at Siligui it is very much essential to know how much solar resource is available. Following Figures & Tables indicate a brief information on the same.

A. *Siliguri, India - Basic information*

Latitude: +26.71
Longitude: +88.43
Time zone: UTC+5:30 hours
Altitude: ~130 m

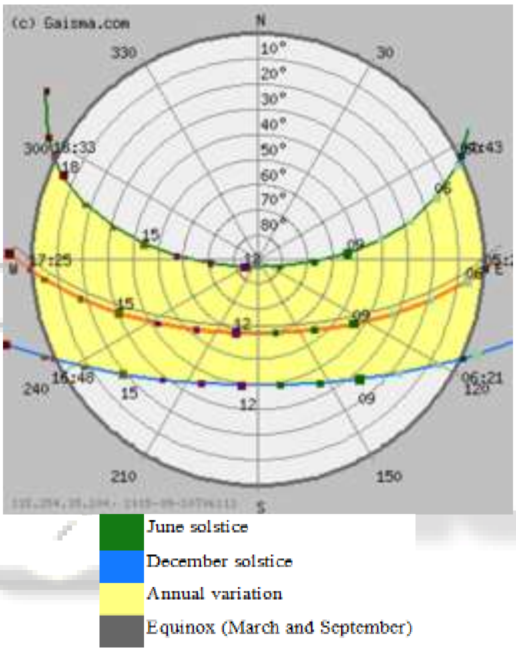

Fig. 2: Sun path diagram

Month	Daily solar radiation – horizontal (kWh/m2/d)	Clearness	Wind speed (m/s)	Earth temperature (°C)
January	4.14	0.53	3.1	14.0
February	4.99	0.49	3.4	17.4
March	5.89	0.49	3.5	22.2
April	6.27	0.46	3.5	23.5
May	6.00	0.46	3.2	23.8
June	4.97	0.43	3.0	24.6
July	4.21	0.39	2.6	24.4
August	4.26	0.38	2.5	24.2
September	4.02	0.41	2.4	23.0
October	4.80	0,52	2.6	20.3
November	4.61	0.56	3.1	16.8
December	4.09	0.57	3.0	14.6

Table 3: Solar Energy And Surface Meteorology
NASA Surface meteorology and Solar Energy: RETScreen Data

These data are useful in comparative study of the system from point of view of cost effectiveness. But other related factors like cost of the system, financing option etc. give significant effect in the entire system.

VI. RESULTS & DISCUSSIONS

The potential for rooftop PV generation using Web-GIS tool [9] in the target area is detailed below. The estimated generation (kWh per Year) for different module type considering fixed, 1-axis tracking & 2-axis tracking array type is tabulated in Table - V.

Location	Siliguri
Weather Data Source	(IN) Gridded 10km Satellite Data 5.2 km
Latitude	26.75° N
Longitude	88.45° E
Array Azimuth	180°
DC System Size	15.0 kW
System Losses	14%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Table 4: Basic information of the planned system

Fig. 3: Satelite imagery of the sample rooftop

Module Type	**Standard**	**Thin film**	**Standard**	**Thin film**	**Standard**	**Thin film**
Array Type	Fixed		1-Axis Tracking		2-Axis Tracking	
Array Tilt	200		200		200	
Average annual solar radiation	5.14		5.83		6.17	
Estimated Generation	20,621	22,003	23,771	25,236	25,040	26,672

(kWh per Year)						

Table 5: Estimated Generation

A. Estimation of levelled Cost of Power from Rooftop PV

An estimation of levelled cost [10] of rooftop solar power for a roof area of 100 sq.m.is as detailed in Table VI.

Capacity	15 kW
Initial Investment	Rs. 11 Lakh
Total kWh generated over 25 years	4,71,974 kWh
Cost per kWh	Rs. 3.73

Table 6: levelled cost of the planned system

VII. CONCLUSION

On the basis of above it can be elucidated that solar energy can be effectively used and roof top PV can be implemented in this selected area of West Bengal i.e. Siliguri. Siliguri has an area of 15.5 sq. km out of which approximately 40% is occupied by residential and commercial establishments. As per 2011 census data total population is 5, 89,092 with 1, 32,124 households. If properly designed and with a long term judicious planning it has a very high feasibility. A detailed investigation with marking of specific areas where roof top PV can be implemented needs to be carried out to find the potentiality of this.

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