Estimation of Roof-top Photovoltaic Potential Using Satellite Imagery and GIS

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***Abstract* —With an estimated 247 million households and a dedicated National Solar Mission, India has a promising roof-top photovoltaic potential. The present paper focuses on developing a strategy for estimating the macro-scale rooftop photovoltaic potential for an area from the satellite imagery for that area, provided by Google Earth^{TM}, with inputs from micro-level simulations. A standard categorization and nomenclature system for the imagesenables macro-scale application. Micro-simulations for rooftop photovoltaic system sizing and design have been carried out in *PVsyst* for different types of buildings and conglomerations. This gives generic factors which enable expansion of the micro-scale results to the macro-level. The procedure has been illustrated for the IIT Bombay campus;extrapolation to macro-scale is in progress.**

***Index Terms* —Area measurement, Energy resources, Geographic Information Systems, Google, Photovoltaic systems,Simulation, Solar power generation**

I. Introduction

The Indian Government has launched the Jawaharlal Nehru National Solar Mission, which aims to achieve a total installed capacity of 20 GW for grid-connected solar power by 2022[1]. The focus is mainly on large centralized solar power stations. However, given the fact that India has an estimated 78.87 million urban households and 167.83 million rural households (according to 2011 census), roof-top photovoltaic systems hold a great promise. Thus there is a need to explore and demonstrate the potential for rooftop photovoltaic systems, at least in some major cities in India with good solar irradiance like Jaipur, Jodhpur, Mumbai, Ahmadabad, Nagpur etc. A major part of India, around an area of 2.0 million sq. km, has an annual DNI of more than 5.0 kWh/m^2/day. Hence there is a significant potential for rooftop PV for the large number of cities and towns falling in this region.

A roof-top solar photovoltaic system consists of one or more solar panels, installed on rooftops of residential, commercial or institutional buildings, thus enabling direct conversion of solar energy to electricity. This system can either be grid-connected or stand-alone. In case the system is grid-connected, the excess electricity generated – over and above the consumption by the building – can be fed to the grid. The surplus electricity is fed back to the grid at a price known as the Feed-in Tariff (FIT), which, in general, is higher than what the grid charges for the consumers. This mechanism has been highly successful in several countries around the globe and is a major incentive for people switching to rooftop photovoltaic systems.

In this paper we develop a methodology for estimating the rooftop photovoltaic potential on a macro-scale for a full city using satellite imagery provided by Google Earth^{TM}, aided by simulations at micro-level. The satellite images have been georeferenced and the total rooftop area calculated using open source GIS software, Quantum GIS (QGIS) 1.8.0. Micro-simulations for rooftop photovoltaic system design and sizing are conducted in *PVsyst*to get generic factors for the estimation at macro-scale. The satellite imagery used for this purpose isfrom the public domain, and thus the method is ready-to-use.

II. Methodology

We have developed a formal convention for categorization, classification and nomenclature of the satellite images for a given area. This has been illustrated for the IIT Bombay campus (area of 2.23 sq. km;average electrical loadof 3500 kW, which peaks to 5000 kW in the afternoon). With a total of 28 buildings in academic area, 15 in hostel area and 147 in residential area, the total built-up area is in excess of 80,000 m^2. The convention facilitates handling large areas at macro scale. We illustrate here the procedure and results for one single image in detail.

A. Satellite Imagery Analysis

Satellite imagery for this analysis is obtained from Google Earth^{TM}. Google Earth^{TM} uses two satellites for providing the satellite imagery, IKONOS and GE-1. The resolution for IKONOS is 0.8m. The resolution for GE-1 is 0.5m. The imagery for IIT Bombay campus is provided by GeoEye's GE-1 satellite, and hence for our case spatial resolution is 0.5m.

B. Image Categorization & Nomenclature

At the said resolution level, the inter-latitude and inter-longitude spacing is 12.96 seconds each. So we have a grid box of 12.96'' x 12.96'', which is divided into two boxes horizontally, for ease of handling. Thus, each image is having dimensions of 12.96" x 6.48" – where the first number represents the width of the picture in direction of increasing longitudes and the second number denotes the length of the picture in direction of increasing latitudes.Fig.1 is a sample image which shows a part of the IIT Bombay campus with the

Fig. 1. Sample Satellite Image for rooftop PV potential estimation

roofs demarcated (only those which lie within the IIT Bombay campus boundary).

Thus, for every grid box, we have two images; and these images are named after the latitude passing on top of the grid box and the longitude passing to the right of the grid box. Hence, the generic name of any image would be <dd-mm-ss x DD-MM-SS POS>.

where,

dd-mm-ss = specifications of the latitude passing on top of the grid box

DD-MM-SS = specifications of the longitude passing to the right of the grid box

POS = will either be N or S, depending on whether the image is positioned in top half of the grid box, or in the lower half.

For example, the image in Fig.1 is the lower of the two images which comprise the grid box between the latitudes 19^{o}07’23.52’’ and 19^{o}07’36.48’’, and longitudes 72^{o}54’25.92’’ and 72^{o}54’38.88’’. So this image has been named as < 19-07-36.48 x 72-54-38.88 S >, whereas the upper image of this same grid box has been named as < 19-07-36.48 x 72-54-38.88 N >

C. Georeferencing

The image has been georeferenced using the Georeferencer plug-in of Quantum GIS (QGIS) 1.8.0. The Coordinate Reference System used for georeferencing is WGS84, and the transformation type is linear. Though the minimum number of control points needed for this transformation type is 3, to ensure greater accuracy, we have taken 5 control points for each image. The georeferenced image is invariably in .tiff format. The Area Measurement functionality of QGIS has been used for calculating the total rooftop area in the georeferenced image.

D. Calculations & Further Analysis

For the case of this sample image, a tabulation of the rooftops has been done:

TABLE I
ROOFTOP AREAS IN SAMPLE IMAGE

Building No.	Area (m^2)	Utilizable Area (m^2)
1	136	121
2	44	40
3	21	19
4	91	81
5	109	97
6	55	49
7	40	36
8	123	109
9	64	57
10	51	46
11	89	79
12	153	136
13	114	102
14	134	120
Total	1225	1093

The Utilizable Area has been estimated from several simulations in *PVsyst* on different types of buildings and conglomerations. For this purpose, anUtilizability Factor (the ratio of roof area available for PV installation to the total roof area)has been estimated from these simulations.

Further, the simulations in *PVsyst* give the ratio for determining Net Module Area from the total Utilizable Area. For the above example, the Net Module Area comes out to be 437 m^2. The sample calculations and results for this sample image have been shown in Table II.

The photovoltaic system efficiency has been taken as 0.12, which is slightly on the lower side. From simulations in *PVsyst*the Performance Ratio for the overall photovoltaic system has been found to be from 0.70 to 0.75. We have taken an overall Performance Ratio of 0.70 for calculation purposes. The solar irradiance data has been obtained from MNRE, as monitored by Solar Energy Centre, MNRE during period 1986-2000.

Thus the methodology has been implemented for the IIT Bombay campus. The load profile and the expected PV generation profile for the academic area, with a rooftop PV plant of 1MW have been shown in Fig.2.

E. Simulations in PVsyst

PVsyst is a software package for design and sizing of photovoltaic systems. Several simulations in *PVsyst*for different types of buildings and conglomerations of buildings have been conducted. Here we show the sample results of one such simulation done for the Mechanical Engineering Department building at IIT Bombay.

TABLE II
CALCULATIONS & RESULTS FOR ROOFTOP PV POTENTIAL OF THE SAMPLE IMAGE

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Global HRZ (kWh/m²/day)	4.6	5.41	6.18	6.62	6.49	4.86	3.74	4.03	4.54	5.00	4.61	4.29
Global POA* (kWh/m²/day)	5.6	6.18	6.50	6.42	5.96	4.87	3.71	3.83	4.57	5.47	5.48	5.22
*global radiation on the Plane of Array (POA) facing south at a tilt of approximately 19 degrees to horizontal												
Gross Monthly Incident Energy (kWh)	75878.1	76308.7	88072.8	84182.8	80756	63858.3	50269.3	51895.2	59924.5	74116.7	71857	70729.3
Gross Monthly Energy Output (kWh) (PV η = 0.12)	9105.4	9157.0	10568.7	10101.9	9690.7	7663	6032.3	6227.4	7190.9	8894	8622.8	8487.5
Performance Ratio	0.7											
Net Monthly Energy Output (kWh)	6373.8	6409.9	7398.1	7071.4	6783.5	5364.1	4222.6	4359.2	5033.7	6225.8	6036	5941.3
Net Annual Energy Output (kWh)	71219.3											

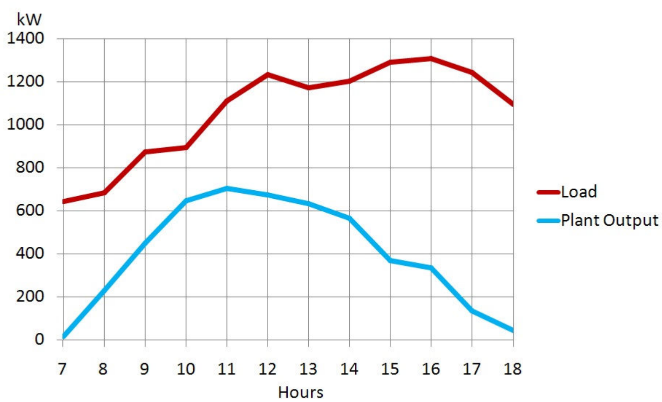

Fig. 2. Typical load profile of academic area at IIT Bombay and expected plant output of a 1 MW plant

The monthly distribution of the useful energy output and the losses from the rooftop PV system for the sample building are shown in Fig.3.

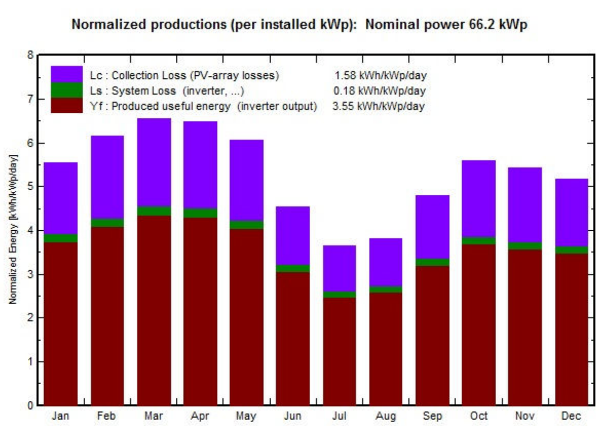

Fig. 3.Monthly energy output and losses for the sample building

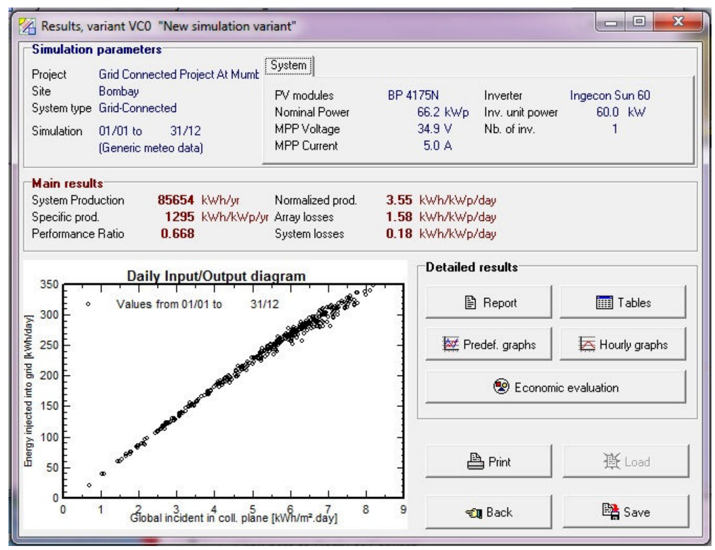

Fig. 4 *PVsyst* Simulation Results for the sample building

The simulations in *PVsyst* give the ratio of Net Module Area to the Utilizable Area to be around 0.4. Also, the overall Performance Ratio for the rooftop PV system has been found to be around 0.70-0.75 from the simulations in *PVsyst*.

F. Flowchart of the methodology

A flowchart for the overall procedure has been shown in Fig.5

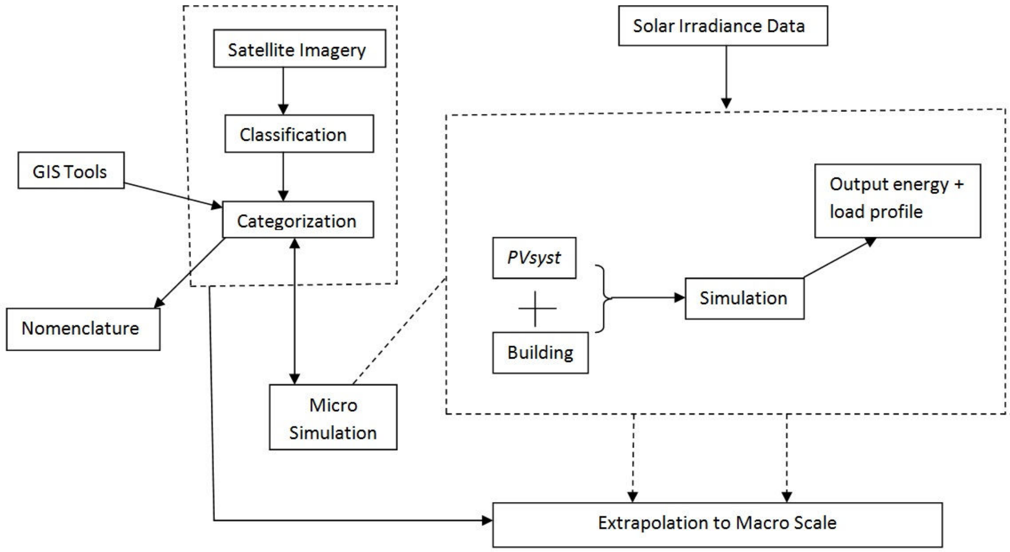

Fig 5. Flowchart of the Methodology

III. Analysis Of The Results

So far, the procedure has been implemented for estimating the rooftop photovoltaic potential of IIT Bombay campus. We are still in the process of extrapolating this procedure to a macro-scale, for a full city.

The micro-simulations in *PVsyst*give important factors like inter-row spacing of PV panels (minimum 0.26 m for Mumbai),Utilizability factor (0.68 – 0.89), ratio of Net Module Area to the total Utilizable Area (around 0.4), Performance Ratio (0.70 – 0.75) etc. These factors are used for estimating the results at the macro-scale.

The macro level application of these concepts is still underway. The results for IIT Bombay campus show that a large share of the total demand (from analysis of the load profile) during the day, especially during the non-rainy season, can be met through the rooftop PV installations.

IV. Significance Of The work

There have been several attempts, by different research groups throughout the globe, at estimating the photovoltaic potential of a region/city or country. Most of these depend on some sort of GIS platform, while others may use empirical or statistical methods.

The present work is significant in that (i) It is based on a unique approach which enables micro-macro synthesis. The micro-level simulations ascertain that the macro-level estimations are accurate and realistic. (ii) It solely depends on the satellite imagery found in the public domain, and hence is free from the complexities and costs associated with acquiring some highly specialized data, like LiDAR, used for the purpose (iii) There is an acute absence of such detailed estimation procedure for renewable technologies in general, and rooftop solar PV in particular, in the Indian context.

At the same time, this analysis can become more accurate if (i) 3-D modeling of the concerned areas can be done with the help of LiDAR or other such sophisticated imaging techniques, (ii) orientation of each individual building can be taken into account.

V. Summary

The present work is a novel method for rooftop photovoltaic potential estimation having the specialized feature of micro-macro synthesis. The satellite imagery has been obtained from Google Earth™. A system of categorization & nomenclature assures extension to macro-scale. The individual images are georeferenced in QGIS. Total rooftop areas have been estimated on an image-wise basis, and the calculations for rooftop potential take help of conclusions from micro-level simulations in *PVsyst*and weather data. The micro-level simulations have been conducted in *PVsyst* for several individual buildings and conglomeration of buildings (both real and artificial neighborhoods). On the basis of the results obtained for the IIT Bombay campus, we are in the process of applying the procedure for a few cities in India with good solar irradiance, like Jaipur, Jodhpur, Nagpur, Ahmadabad etc,

VI. Acknowledgement

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References

[1] Tarun Kapoor, *Grid Connected Solar Power in India,* MNRE, Government of India, 2012

[2] Campbell, J. B, *Introduction to Remote Sensing,* New York London: The Guilford Press, 2002.
[3] M.A.H. Mondal, A.K.M.S. Islam., "Potential and viability of grid-connected solar PV system in Bangladesh", *Renewable Energy,* 36, pp. 1869-1874, 2011
[4] J. Ordonez, E. Jadraque, J. Alegre, G. Martinez., "Analysis of the photovoltaic solar energy capacity of residential rooftops in Andalusia (Spain)", *Renewable and Sustainable Energy Reviews,* 14, pp. 2122–2130, 2010
[5] L. Bergamasco, P. Asinari, "Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: application to Piedmont region (Italy)", *Solar Energy*, 85, pp. 1041–1055, 2011
[6] J. A. Jakubiec, C. F. Reinhart, "Towards validated urban photovoltaic potential and solar radiation maps based on LiDAR measurements, GIS data, and hourly DAYSIM simulations" in*SimBuild 2012, 5th National Conference of IBPSA-USA,* Aug.1-3, 2012, Madison, Wisconsin
[7] Clean Energy Council, "Tech Info: PV array row spacing" in*Energy Efficiency and Renewable Energy Bulletin*, March 2010

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