Assessment of Rooftop PV Potential in Kolkata using various Solar Cell Technologies

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Abstract— Kolkata is a metropolitan city covering an area of 185KM2 and is one of the most densely populated cities in the world. According to West Bengal Renewable Energy Development Agency (WBREDA) policy, there is a target to harness 16MW of solar rooftop and smaller solar installations in the state by 2017. Assuming theoretically available roof space for rooftop PV systems is 30 percent or 39000m2 of built up area in Kolkata city, 25% of the 16MW target set by the state’s nodal agency can be met by solar rooftop installations by using crystalline silicon or thin film technologies such as CIGS and CdTe. The transmission and distribution losses amounts to 13% in Kolkata can be reduced as power is consumed at the point of generation. Environmental impacts associated with coal-based power plant such as land use and habitat loss, water use, use of hazardous chemicals in power generation can be avoided with rooftop solar PV power plants.

Key words: Solar rooftop, PV technologies, Generation, Emission reduction

I. INTRODUCTION

The Solar rooftop PV power plant allows utility customers to generate their own electricity and reduce their electric bill and the surplus PV generated power is fed into the grid through netmetering facility. It cuts down dependency on grid power and diesel generator.

Kolkata, formerly Calcutta is more than 300 years old city located in the Ganges delta, is the capital of West Bengal and former Capital (1772--1911) of British India, covering an area of 185 KM^2 [1].

Its climate is influenced by the sea, Bay of Bengal. The annual mean temperature is about 27^0C and monthly mean temperature is 19^0C to 30^0C. But during the dry spell the temperature may exceed maximum 40^0C in the month of April-May. Kolkata is predominantly warm and humid. The diffuse fraction of solar radiation is quite high due to cloud cover, and the radiation can be intense on clear days. It is one of the most densely populated cities in the world [2].

The city has Calcutta Electric Supply Corporation CESC Ltd to provide 100% of the power consumption needs. The CESC’s electricity generation is mainly coal based. The total power consumed by the city in the financial year 2013-14 was 9912 million units of which 1721 million units[3] were purchased from other power generating companies.

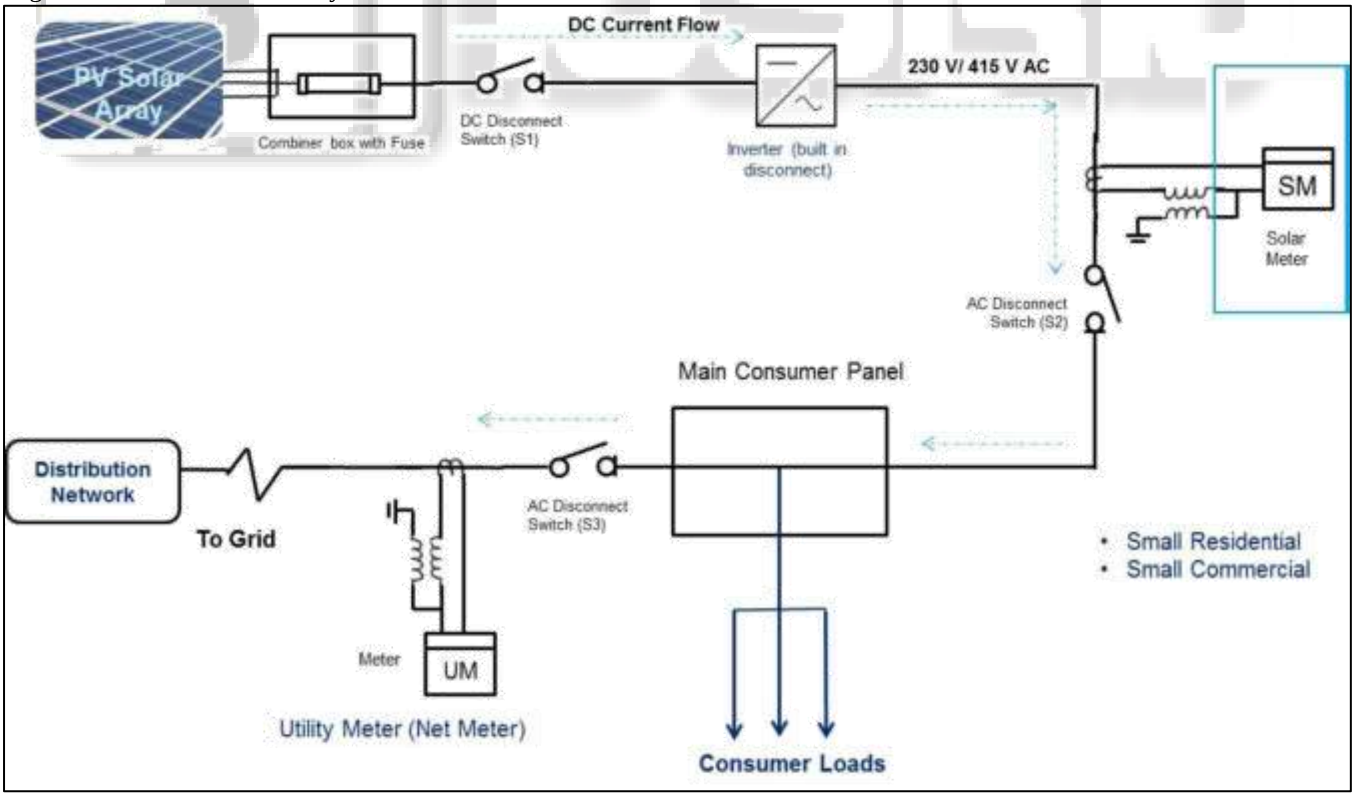


Fig 1: Solar Rooftop PV Power Plant

Source: SECI, Govt. of India

The existing installed capacity of Renewable Energy Sources in West Bengal stands at 193MW[4]. Eventhough there is huge potential to generate Solar Electricity, still state nodal agency could not install more than 2MW (on-Grid)[4] since 2010. The lack of available space for ongrid solar PV in a highly urbanized and congested city like Kolkata is often considered as a key barrier for the government to reach to it's target of 500MW (on-grid & off-grid) by 2022[4].

II. ROOFTOP POTENTIAL

According to West Bengal Renewable Energy Development Agency (WBREDA) policy, there is a target to harness 16MW[4] of Solar rooftop and smaller solar installations in the state by 2017. Kolkata is the only district in West Bengal where employment, developed infrastructure, educational, cultural, shopping malls and high-raised residential buildings etc. are centered. So 30% of the target can be achieved from this city roof area itself.

The total area covered by Kolkata city is 185KM^2 of which 70 percent or 130KM^2[5] is built up area excluding roads, parks, big play grounds etc. and assuming theoretically available roof space for rooftop PV systems is 30 percent or 39Km^2 of built up area.

A. PV Technologies

Technology	Highest Lab efficiency (%)	Highest Module efficiency (%)
Single Crystalline (c-Si)	25.6	22.9
Multi Crystalline (c-Si)	20.8	18.5
Copper Indium Gallium Selenide (CIGS)	20.5	15.7
Cadmium Telluride (CdTe)	21.0	17.5

Table 1: Efficiencies of various PV technologies

Ref: Solar cell efficiency tables (Version 45) Martin A. Green, Keith Emery, Yoshihiro Hishikawa, Wilhelm Warta and Ewan D. Dunlop. Progress in Photovoltaics: Research and Applications Prog.Photovolt:Res.Appl. 2015; 23:1–9. Module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25 °C (IEC 60904-3: 2008, ASTM G-173-03 global).

Traditionally, crystalline silicon technology had been the preferred choice of the PV market place all over the world due to its higher energy conversion efficiencies and easy availability. But they have low absorption coefficient, thus require 200-300 microns thick material for efficient light absorption therefore increasing the cost of the material. For crystalline Si solar cells, for every 1^{o}C increase in temperature above 25^{o}C, the decrease in the value of voltage is -2.3mv, temperature coefficient is -0.45% /^{o}C[6].

Thin Film technologies like CIGS and CdTe offers high absorption coefficient therefore very thin material of 1-2 microns[7] is enough to absorb most of the light incident on the solar device hence significant cost savings can be achieved. A very important advantage of CIGS and CdTe is that they can be deposited on flexible substrates by roll and roll process, allowing new applications, like building integrated PV. The temperature coefficient of CIGS is -0.36% /^{o}C and CdTe has -21% /^{o}C.[8] The reduction in power per degree rise in temperature of CIGS and CdTe is less compared to crystalline silicon.

Soon Thin Film CIGS and CdTe technologies will become cost competitive with Si.

III. METHODOLOGY

Whole India including Kolkata city lies in the northern hemisphere and the solar module should be facing south and should be inclined to an angle equal to the latitude of that location so that maximum irradiance captured.

Kolkata: Latitude 22.566^{o}N and Longitude 88.366^{o}E		
Annual global solar radiation = 1805KWh/m^2-year[9]	Annual global solar radiation at plane of angle equal to latitude = 2010KWh/m^2 –year[10]	annual sunshine hours = 2445 hours[9]

Crystalline Silicon solar cells require 7-8m^2 of surface area to generate 1KWp, about 10m^2 using thin film technologies such as CIGS and CdTe.[11] Assuming theoretically available roof space for rooftop PV systems is 30 percent of built up area or 39000m^2 in Kolkata city.

SPV Technology	Installed Capacity in 39000m^2 area
Crystalline Silicon (c-Si)	**4. 875MWp**
CIGS	**3.9MWp**
CdTe	**3.9MWp**

Table 2: Installation Capacity

Annually Energy generated without losses = PV plant capacity X annual sunshine hours ……..1

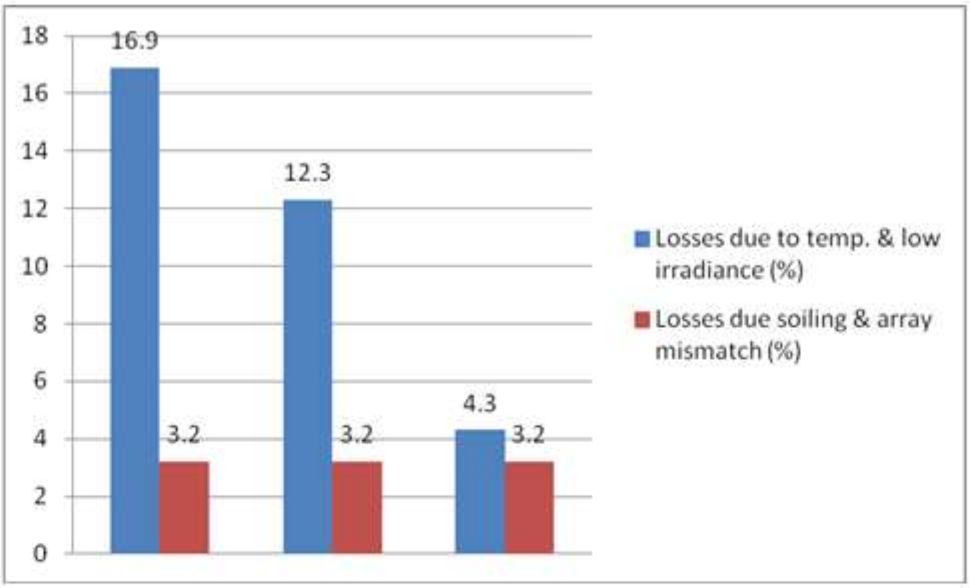
Energy generated after considering module losses = Energy generated without losses X [1 - PV modules losses] ………...2

Annual Energy Production	Losses due to temperature and low irradiance[10]	Losses due array soiling and mismatch [6]	Generation after considering losses
Crystalline Silicon	16.9%	3.2%	**9.5 Million units**
CIGS	12.3%	3.2%	**8.1 Million units**
CdTe	4.3%	3.2%	**8.9 Million units**

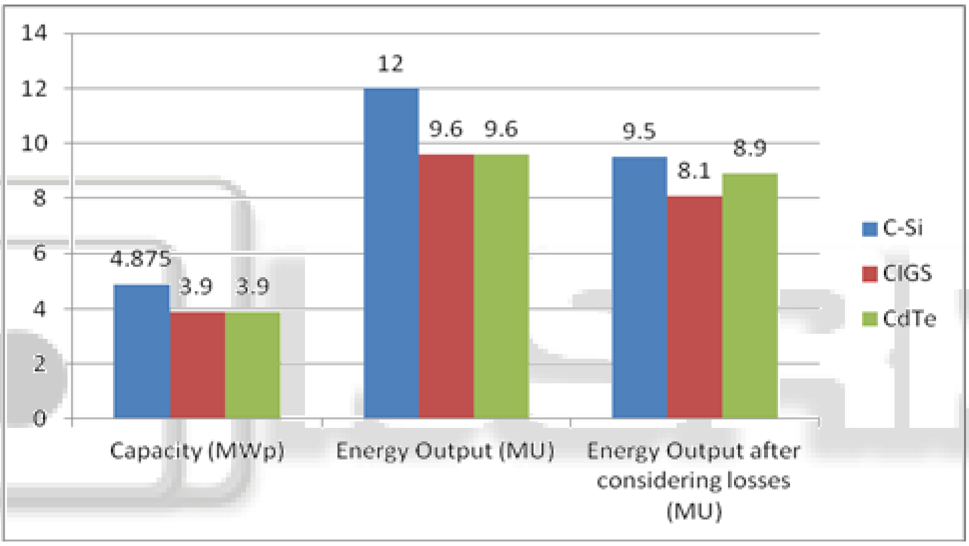
Table 3: Energy production after considering losses

IV. RESULTS AND DISCUSSION

The most important point that is highlighted here is thirty percent of the built up area can be used for rooftop solar installation to meet the 25% of the 16MW target set by the state's nodal agency. Table 2 and Table 3 show the area required by and the generation units of crystalline silicon and thin film technologies such as CIGS and CdTe.



Graph 1: Losses due to temp., low irradiance, soiling and mismatch in various PV technologies



Graph 2: Capacity vs Generation

Eventhough the generation losses are lower in thin film technologies as shown in the Graph 2 but the power generation is still lesser compared to crystalline silicon technology, since the efficiency of c-Si is superior to all the PV technologies till now. It is also observed, the generation unit of CdTe technology is higher to CIGS since the generation loss of CdTe plant is comparatively very low as shown in the Graph 1.

A. Co_2 Emission Reduction

The fast urbanization, increasing traffic, economic growth trajectory, industrialization and higher level of energy consumption has resulted an increase in pollution load in the Kolkata urban environment. The Kolkata is one among the worst affected city in terms of air pollution and ranks 46th in Asia.[12] Study conducted by Central Pollution Control Board (CPCB) has projected the thermal power plants responsible behind this worst air quality.

CO_2 emission = Power generation from Solar power plant (MWh) X

Electricity emission factor (tons CO_2/ MWh)………3

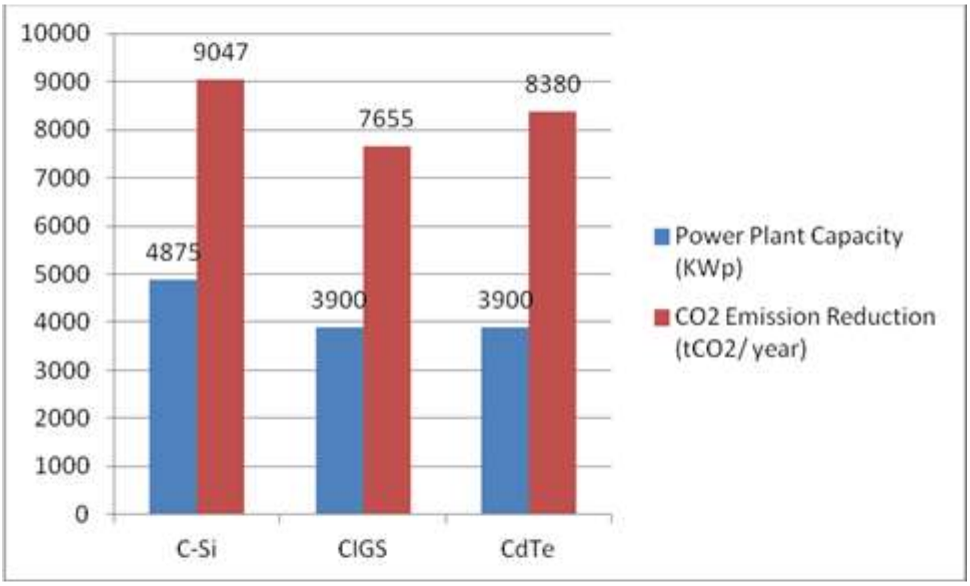
Where,

Electricity emission factor for India is 0.950tCO_2/ MWh.[13]

SPV Technology	Installed Capacity	Generation after considering losses	**CO_2 emission reduction**
Crystalline Silicon (C-Si)	4. 875MWp	9.5 Million units	**9047t CO_2/ year**
CIGS	3.9MWp	8.1 Million units	**7655t CO_2/ year**
CdTe	3.9MWp	8.9 Million units	**8380 t CO_2/ year**

Table 4: CO_2 emission reduction

Environmental impacts associated with coal-based power plant such as land use and habitat loss, water use, use of hazardous chemicals in power generation can be avoided with rooftop solar PV power plants.



Graph 3: PV plant capacity vs CO_2 Emission reduction

V. Conclusion

An average building can accommodate minimum 1-3KWp[14] of solar rooftop PV power plant and larger roofs can accommodate larger capacities. It reduces requirement of land in a highly urbanized city. The transmission and distribution losses amounts to 13%[15] in Kolkata can be reduced as power is consumed at the point of generation. Commercial rooftop solar installations will reach cost parity with imported coal next year, reaching complete parity for both the cost of generation (levelised cost of electricity, or LCOE) and also to end users (levelised cost of power, or LCOP) by 2024.[16] The advantages of Thin film PV modules are- cheaper and low generation losses than c-Si modules, but their efficiencies are also lower than c-Si. Due to high energy conversion efficiencies and easy availability still c-Si is dominating in PV market.

References

[1] Census of India 2011 provision data, accessed at www.census2011.co.in/density.php
[2] Indian Metrological Department. www.imdkolkata.gov.in/tourist/kolkata_tourism_weather_info_1.pdf
[3] Annual Report 2013-14 by Calcutta Electricity Supply Corporation (CESC) Ltd.
[4] Policy on Co-generation and Generation of Electricity from Renewable sources of energy by Department of Power & Nonconventional energy sources, Govt. of West Bengal.
[5] Inputs provided by Kolkata Municipal Corporation (KMC).
[6] Chetan Singh Solanki Solar Photovoltaic Technology and Systems, A manual for technicians, trainers and engineers book. PHI Learning Private Limited.
[7] Harry Efstathiadis and Adam Filios. Handbook of Research on Solar Energy Systems and Technologies. CuInGaSe based Thin Films for Photovoltaic Solar Cells.
[8] A. Virtuani, D. Pavanello and G. Friesen. Overview of temperature coefficients of different Thin Film Photovoltaic technologies.
[9] Mani. Handbook of Solar Radiation Data for India. Allied Publishers, New Delhi.
[10] PVGIS – Photovoltaic Geographical Information System (PVGIS) provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia.
[11] Paul A. Lynn. Electricity from Sunlight: An Introduction to Photovoltaics book. WILEY Publications.
[12] www.timesofindia.indiatimes.com
[13] Sustainable Energy Project Support Baseline Calculation by Wuppertal Institute for Climate, Environment and Energy GmbH.
[14] Mr. Rakesh Kumar (Director) PV Systems, Solar Energy Corporation of India (SECI), Govt. of India. Rooftop Solar PV Systems PPT.
[15] Draft Report of 18th Electric Power Supply Survey (EPC) of India (Volume-II) by Central Electric Supply. Govt. of India.
[16] Evolution of Solar in India - report published by Tata and Bridge to India.

