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 KM²[1].

Its climate is influenced by the sea, Bay of Bengal. The annual mean temperature is about 27°C and monthly mean temperature is 19°C to 30°C. But during the dry spell the temperature may exceed maximum 40°C 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.

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 on-grid solar PV in a highly urbanized and congested city like Kolkata is often considered as a key barrier for the government to reach to its 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\(^2\) 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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Highest Lab efficiency (%)</th>
<th>Highest Module efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Crystalline (c-Si)</td>
<td>25.6</td>
<td>22.9</td>
</tr>
<tr>
<td>Multi Crystalline (c-Si)</td>
<td>20.8</td>
<td>18.5</td>
</tr>
<tr>
<td>Copper Indium Gallium Selenide (CIGS)</td>
<td>20.5</td>
<td>15.7</td>
</tr>
<tr>
<td>Cadmium Telluride (CdTe)</td>
<td>21.0</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Table 1: Efficiencies of various PV technologies


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°C increase in temperature above 25°C, the decrease in the value of voltage is -2.3mv, temperature coefficient is -0.45% /°C\(^5\).

Thin Film technologies like CIGS and CdTe offers high absorption coefficient therefore very thin material of 1-2 microns\(^5\) 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% /°C and CdTe has -21% /°C.\(^6\) 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.

### Table 2: Installation Capacity

<table>
<thead>
<tr>
<th>Area</th>
<th>Energy generated without losses</th>
<th>PV plant capacity X annual sunshine hours</th>
<th>Energy generated without losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>39000m(^2)</td>
<td>10MWp</td>
<td>2445 hours</td>
<td>8.9 Million units</td>
</tr>
</tbody>
</table>

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.\(^1\) Assuming theoretically available roof space for rooftop PV systems is 30 percent of built up area or 39000m\(^2\) in Kolkata city.

### Table 3: Energy Production after considering losses

<table>
<thead>
<tr>
<th>Technology</th>
<th>Losses due to temperature and low irradiance(^{10})</th>
<th>Losses due to array soiling and mismatch (^{6})</th>
<th>Generation after considering losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalline Silicon</td>
<td>16.9%</td>
<td>3.2%</td>
<td>9.5 Million units</td>
</tr>
<tr>
<td>CIGS</td>
<td>12.3%</td>
<td>3.2%</td>
<td>8.1 Million units</td>
</tr>
<tr>
<td>CdTe</td>
<td>4.3%</td>
<td>3.2%</td>
<td>8.9 Million units</td>
</tr>
</tbody>
</table>

### Table 4: Energy production after considering losses

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.
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Even though 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. \( \text{CO}_2 \) 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.

\[
\text{CO}_2 \text{ emission} = \text{Power generation from Solar power plant (MWh)} \times \text{Electricity emission factor (tons CO}_2/\text{MWh)}
\]

Where,

Electricity emission factor for India is 0.950tCO\(_2\)/MWh.\(^{13}\)

<table>
<thead>
<tr>
<th>SPV Technology</th>
<th>Installed Capacity</th>
<th>Generation after considering losses</th>
<th>( \text{CO}_2 ) emission reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystalline Silicon (C-Si)</td>
<td>4, 875MWp</td>
<td>9.5 Million units</td>
<td>9047t CO(_2)/year</td>
</tr>
<tr>
<td>CIGS</td>
<td>3.9MWp</td>
<td>8.1 Million units</td>
<td>7655t CO(_2)/year</td>
</tr>
<tr>
<td>CdTe</td>
<td>3.9MWp</td>
<td>8.9 Million units</td>
<td>8380 t CO(_2)/year</td>
</tr>
</tbody>
</table>

Table 4: \( \text{CO}_2 \) 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.
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 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.

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