Data-Driven Predictive Modelling for Solar Insolation using Artificial Neural Networks

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**Abstract-** Enhancing efficiency of photovoltaic (PV) cells while keeping the cost down in an effective manner is a challenging endeavor in PV industry. Planar micro optical solar concentrator cells are presently the most advanced type of cells in solar industry. In this paper we present a new approach to increase the efficiency of solar cell known as Micro-Hole PV cell technology. Where sun light is collected by the primary focusing optic that consist of well establish two dimensional lens array. The secondary homogenization optic will be a wave guide. The beams of light will be concentrated by the lens array on to prism shape coupling facets with micro holes. The micro holes will be embedded into the PV cells up to the regions where maximum amount of electron hole pairs are created i.e. the depletion layer. Once the light enters the micro hole it will be absorbed almost fully by the PV cell. Our concept will not only increase the efficiency but will also be cost effective. The micro-hole technology is to ensure that the maximum amount of light incident on the solar cell gets absorbed.

**Keywords**-micro hole, PV, TIR, solar, cell, light management, Photovoltaic.

**I. Introduction**

At present, only 0.1 percent of the total generated electricity comprises of green energy like solar, wind, tidal etc [6]. This ratio of green power generation has remained low because of its high initial cost and low power production. Total reservation of fossil fuels decrease day by day and nuclear power become more controversial topic for earth ecosystem. That's why green energy becomes more important for future world. Solar is the reliable and available energy source through the whole world.

In solar cells, solar thermal or photon energy is absorbed in semiconductor materials that produce electron hole pairs in the cell, the movement of which results in the production of photo current and produce photo-electricity through the material. But in order to do so the solar light has to be captured first and that too very efficiently. That is where a high efficiency Concentrator photo voltaic system plays a vital role. It is the job of these concentrators to gather light and efficiently relay it to the PV cell. Efficient light management can be brought about by reducing incident light reflection. It is one of the approaches to enhance existing solar cell efficiency [7]. Surface reflection is dependent on the refractive index and incident angle. Planar micro-optic solar concentrator (PMOSC) is one way to minimize the surface reflection [4]. The PMOSC system uses two dimensional optical lenses to collect light and this concentrator focuses the light at a point. The focused light when passed to a waveguide coupler homogenizes the rays from the individual lenses and transmits it to the PV cell. Focused light is not concentrated at a specific point, this light covers a circular shape region and interestingly follows Gaussian shape. We discussed the use of better absorption geometry in the form of micro holes that can increase collection efficiency drastically.

In case of solar optics incident angle and refractive index are the most important property that we come across and should be concerned about when designing concentrators. Most of the solar rays in 300-1100 nm range at AM1.5 have the highest intensity around about 0-1 Wcm-2 [1]. Penetration depth and total internal reflection are most crucial light properties that effect micro-hole PV cell.

**II. Optical Concentrator**

Optical concentrators use two dimensional optical lenses [4]. This concentrator design followed Jason H. Karp's PMOSC. In recent solar industry it is a well establish concentration device owing to its cost effectiveness as it is coherent with the existing roll technique of manufacture. Here most of the solar ray falls on the surface of the concentrator it focuses the light on to the surface of the PV cell.

Light has wave particle duality property. That's why light behaves as a particle and also as wave [1]. It is the cross product of electric and magnetic wave. Light reflection from a surface is dependent on the two things one is refractive index which comes from Snell's law and the other thing is polarity of electric field of the light [2]. Basically sun light is not polarize but if we look at the two extreme cases one of perpendicular and other is parallel polarization with the normal then it is possible to infer what happens for other cases. If we look at Fig 1 then we can find that most rays experience 0-45 incident angles. This is the case when solar devices align with the sun. If we look at the computer simulation (Fig 2) for incident angle then we can easily find that with the changing of the angle

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Fig 1: Incident ray on the lens dome

percentage of reflected light for micro concentrator is around 20 percent for 0 -45 angle. In this simulation result we find that for PMOSC device surface reflection is 20-28 percent of total coming ray. But if we are looking at planar surface reflection for glass, there are two types of effects, one is for parallel electric field and other is perpendicular electric field. These two types of reflection basically follow the rule of equations 1 and 2 where n= n2/ n1. For alignment with sun coming ray experience 20-28 percent surface reflection, but high quality optical glass like flint glass can maintain 92 percent of original energy [3].

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Fig 2: Simulation of Reflected light with respect to surface incident angle in dome surface

From the Fig 2 we are able to detect that if incident surface is planar then with the change of incident angle percentage of reflecting light is increasing and when incident angle is more than 85 degree than reflectance is more than 90 percentage.

--------------(1) --------------(2)

Form this simulation we find another important fact; if we are looking at parallel electric field than we can see for 55 degree incident angle reflection is almost zero at the dome surface.

**III. Concentrator Light Management**

In Micro-hole solar cell system 80 percent incident light gets in the device and here the most important thing is light management. If we consider the Fig 3 then we are able to visualize how incoming rays fall on the semiconductor material. From fig 4 we find that for surface reflection, more than 38 percent light is reflected back into the previous guided medium. Here the refractive index of the guided medium is 1.55 and that of the optical concentrator is 1.5. Most of the

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Fig 3:Light reflection in semiconductor surface & Zigzag surface reflector

reflected back light has angles less than critical angle [2]. That's why this light is decoupled and comes out form the device. In order to make these angles greater than critical angle we see the use of a zigzag semiconductor surface.

Fig 4 shows that reflector surface which makes the incident angle greater than critical angle. Owing to the zigzag surface, light is trapped in the device and it cannot come out [7]. It is due to this that the total internal reflection of the device increases. But the problem is if we look at Fig 4 we can see that only 62 percent of the light is absorbed. Large incident angle increases the ratio of the reflection. Here the guided medium's refractive index is very close to the concentrator’s refractive index. Therefore the guided mediums critical angle is more than 75 degree. That's why for more than critical angle 38% of the light is guided (fig 4). So, for enhancing efficiency of light absorption quantity we have to look for a different approach. The approach should allow us to tackle this problem and improve the present efficiency.

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Fig 4: Simulation of Reflected light with respect to surface incident angle in semiconductor surface.

**IV. Design of Micro-Hole**

For concentrator light management we make a zigzag surface which helps to create desired critical angles in order to maintain the light within the waveguide. Form Fig 4 we can see that more than 38 percent of the rays are guided through the guided medium. To reduce the surface reflection form the zigzag surface we make micro level holes on the semiconductor material. The micro-hole then increases the absorption coefficient.

Designing a micro-hole is the most important aspect for the micro-hole solar cell. It uses two light properties one is absorption and another is surface reflection. But in micro-hole we can consider both light reflection and absorption quality. If any photon gets in to the hole then it bounces back and forth on the surface of the hole eventually at the end it is absorbed by the semiconductor device. Before designing micro hole we have to consider one important thing and that is the absorption coefficient or penetration depth. From absorption Coefficient graph we are able to find out the penetration depth of Si material [1]. For 400nm light penetration depth is 100nm and for 1100nm it is around 100µm. But in air AM1.5 400nm to 800nm has maximum intensity and for 800nm penetration depth is 10µm.[1]

The micro-hole is organized on the solar surface like Fig 5. Spacing of the adjacent holes is an important issue. If the adjacent holes width is less than the penetration depth then coming light is penetrated from one hole to another hole. Then this technique is unable to serve its purpose efficiently for the device. That is why here the minimum

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Fig 5: Micro-hole orientation & spacing

spacing in-between the holes is 10µm or 1/α. In the device the holes are oriented as in Fig 5. If we consider a particular hole at a distance of 1/α or penetration depth with all adjacent holes, then we can see that each hole basically covers an area which is the subset of the area of a hexagon. This hexagon has 6 triangle and each triangle area is (penetration depth.For this device 1/α=10µm to 100µm. For micro-hole PV device we chose each hexagon in such a way that each hexagon cell contains one hole; adjacent holes distance is equal to the penetration depth. Thus if we take this type of microcell then a 1 semiconductor device contains 1.1547 to 1.1547 microcells on the device for 100µm and 10µm penetration depth. This huge amount of micro-holes is oriented in the two dimensional form as shown in Fig 5.

Micro-holes cover the 90.69 percent of the total area thus 90.69 percent of the light on a unit area gets into the micro-hole. When a ray gets on the micro hole then it is fully absorbed in there. If we take a look on the Fig 6 then we can see that incoming light is going back and forth on the cylindrical walls of the micro hole and at the end is absorbed by the device. That means if any photon gets in these cylindrically shaped holes then the photon cannot come out form the micro-hole. Here we see that by using micro-hole we can cover 90.69 percent of the total area of a device. The Fig 7 shows a computer simulation of the effect of hole radius, we can see the increase of the micro-hole radius for different adjacent distance in a fixed area of the cell; where cell area is varying with penetration depth. And the absorption of light is increasing with the increasing of radius. In another way we can say that if we use maximum radius then only 3.5 percent light are reflecting back to the previous medium. In the same time if we use planar semiconductor surface then 38 percent of total light is reflecting back. In Fig 7 for different penetration depth shows absorption ratio. But for 20-30µm it covers 800-900nm region; which is basically AM1.5 higher intensity region.

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Fig 6: Micro-hole light absorption

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Fig 7: Semiconductor reflection with respect to radius of the micro-hole

Form micro-hole simulation we know that 3.5 percent light are reflected back to the previous medium. This 3.5 percent light are guided through the guided medium and comes out form the edge of the device. That's why this 3.5 percent light is loss for the device. Form Fig 4 we can see that maximum absorption is 62% for semiconductor material. And around 9% of light falls on the plane surface and gets back to the previous medium. If we leave the edges open then this 3.5 percent ray is lost. To utilize this amount of ray we can set very small length micro-hole PV cell on the edge of the surface. This will be in series with the original solar cell(fig 8).

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Fig 8: Full Micro-hole solar cell system

**VI. Conclusion**

The target of the whole paper was to demonstrate how, simple changes in the cell geometry has had a considerable impact on the efficiency of absorption of light. Our paper stresses on the use of micro holes to increase absorption. These Concentrator photo voltaic system relies upon inexpensive concentrator optics and assembly to offset the high cost of very efficient solar cells. The use of these techniques will insure that more percentage of light is captured and transformed to photo electricity.

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