Using structured aluminum reflectors in flux scattering on module performance

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Abstract: The current energy production from fossil fuels and nuclear energy has environmental drawbacks. These drawbacks include the creation of nuclear waste, and the pollution associated with fossil fuels which lead to global warming and climate change. It is apparent that an alternative and sustainable source of energy must be found. A potential solution to this problem is solar electricity. Currently, solar panels are expensive and hence un-economical for most buyers**.** The use of solar concentrators creates a potential for less expensive electricity because concentrators raise the amount of incident radiation over a relatively small area of the absorber. The reduction in cost is achieved by reducing the module area and the use of low-cost reflectors. However, specular reflectors cause high concentrated heating and form hot spots on the solar module cells. These hot spots are a result of uneven concentration of radiation. The overall effect is the reduced fill-factor and overall efficiency of the system. In this paper, we report an alternative solution to the problem of non-even illumination by using locally available low-cost semi-diffuse reflector with four different groove orientations scribed on it so as to scatter the radiation flux onto the module. The groove orientations were plain sheet (NG), horizontal grooves (HG), vertical grooves (VG), and the crisscross groove (CG) orientations. Our results show that the locally purchased semi-diffuse aluminium structure can be used as a booster reflector compared with the commercial high specular reflector.

Keywords*: Semi-diffuse, specular, fill-factor, non-even illumination, low-concentration*

1. Introduction

The costs of solar panels compared to the amount of power they produce make their purchase un-economical for most end-users**.** The use of solar concentrators create a potential for producing less expensive electricity by replacing expensive solar cell area with inexpensive optical materials such as plastic refractors or metal reflectors. Currently, mirror-like reflectors (specular materials) are used for solar thermal applications while lenses are used in photovoltaic systems. The use of lenses in photovoltaic (PV) may not reduce the cost of electricity to affordable levels because they are expensive. Highly specular materials have high reflectance and are good in imaging optics for high concentration, whereas semi-diffuse reflectors are preferred in non-imaging optics for flux scattering. The module cost could be reduced if low-cost materials are used to concentrate solar energy flux across a small module area [1,2]. In this paper we address two of the problems faced with concentrating photovoltaic systems namely; non-even illumination and use of expensive lenses and specular materials as reflectors by designing, constructing and evaluating a low concentrator system, using locally available low-cost semi-diffuse aluminium structure reflector with four different groove orientations scribed on it to improve on the fill-factor (FF) of the module for low cost electricity. Fill-factor is an important parameter that tells the overall performance of the solar module. A solar module with a high fill-factor is able to produce high power for a longer period of time. Therefore, by improving the FF of the module we are increasing both the power output and the durability of the module [3].

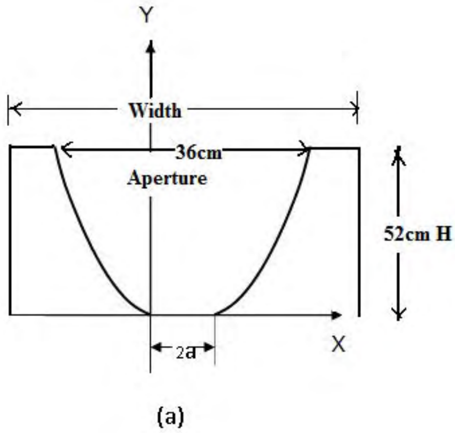
2. Methodology

2.1. Design and construction of the compound parabolic concentrator (CPC)

We first designed the Compound Parabolic concentrator (CPC) using the standard polar co-ordinate system proposed by Winston [4,5]. The value of a which is the half width of the exit aperture was determined after deciding on the size of the solar module string to be used after which the acceptance half angle θ of the CPC was decided while Φ varied from 5° to 107° in our case. The determined values of a and θ in this case were (a=5cm and θ=15°) which we then used in equations (1) and (2) to generate the X and Y co-ordinates. These co-ordinates were then plotted on the graph paper to design the CPC which was later constructed .Figure 1 shows the CPC designed (a) and the actual constructed Compound Parabolic Concentrator (b) used for the current-voltage (I-V) measurements.

$$x = \frac{2f\sin(\phi-\theta)}{1-\cos\phi} - a \qquad (1)$$

$$y = \frac{2f\cos(\phi-\theta)}{1-\cos\phi} \qquad (2)$$



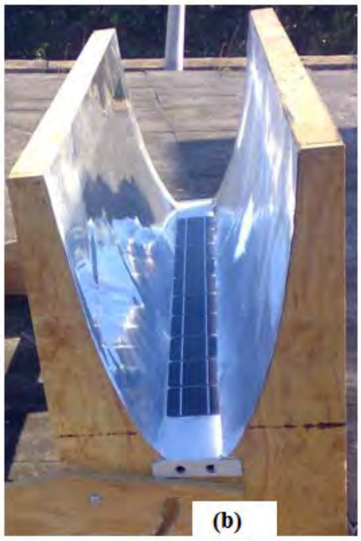


Fig 1. Shows the CPC design from polar co-ordinates into the X-Y co-ordinates system (a) and the actual compound parabolic concentrator constructed (b).

2.2. Spectral reflectance of structured aluminium

An ideal reflector material for solar electricity production should have a relatively high reflectance in visible and ultra violet regions of the solar spectrum and to maintain this relative high reflectance for the entire life of the solar system [6].

In this experiment we used one reflector material (semi-diffuse aluminium structures), but with four different orientations of the grooves namely; plain (NG) (no grooves), horizontal grooves (HG) vertical grooves (VG) and criss-cross groove (CG) orientations as shown in Figure 2. The groove sizes ranged between 2mm to 3mm. Our aim was to determine which of these four orientations was able to provide uniform illumination and a better fill-factor improvement using the named reflector .The optical properties of this reflector material were obtained from the Perkin Elmer spectrophotometer lambda 900. The total integrated reflectance (TIR) was calculated from equation (3). The TIR gives the overall reflectance of the material the property that shows how much flux the material is able to scatter.

$$R_s = \frac{\sum_{305nm}^{2450nm} R(\lambda).G(\lambda).\Delta\lambda}{\sum_{305nm}^{2450nm} G(\lambda).\Delta\lambda} \qquad (3)$$

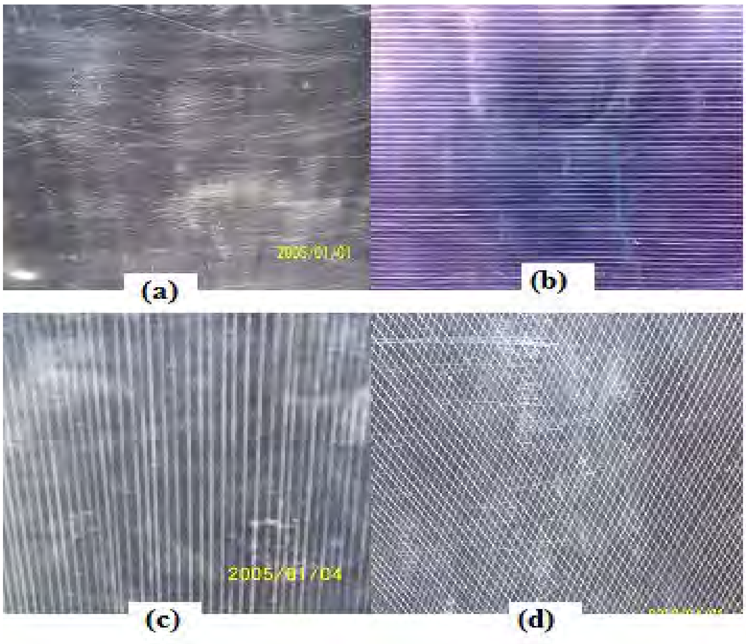


Fig 2. Showing the four different orientations of the grooves on the semi-diffuse structured aluminium:(a) plain sheet (NG) (b) horizontal grooves (HG) (c) vertical grooves (VG) and (d) criss-cross grooves (CG)

2.3. Current-voltage (I-V) curve measurement.

The current and voltage generated by the module under concentration was measured using the current-voltage tracker instrument obtained from Vattenfall, Sweden .The short-circuit current *Isc*, the open-circuit voltage V_{oc}, the power maximum P_m, the maximum current I_m, and the maximum voltage V_m were extracted from each I-V curve. The fill-factor (FF) was evaluated from equation (4).

$$FF = \frac{I_m.V_m}{I_{sc}.V_{oc}} = \frac{P_m}{I_{sc}.V_{oc}}. \qquad (4)$$

3. Results

3.1. Measurement of Total Integrated Reflectance(TIR)

Table 1 shows that the plain sheet (NG) was a better reflector with TIR of 89% followed by the criss-cross grooves (CG) orientations with 88%, the horizontal grooves (HG) orientation was the third best with 85% while the vertical orientations of the grooves on the aluminium structure was the least with 82%, as measured by the integrating sphere in the lab.

Orientation	Total Integrated Reflectance (TIR)
NG	89%
HG	85%
VG	82%
CG	88%

3.2. Fill-factor comparison at 0° (normal)

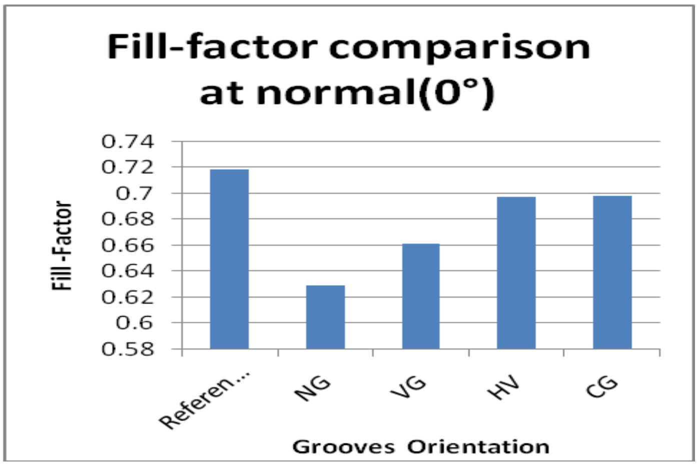


Fig.3 Fill-factor comparison at 0°

The results for the fill-factor comparison revealed that the criss-cross grooves (CG) gave the highest fill-factor followed by the horizontal grooves (HG) and then the vertical grooves (VG). The plain sheet had the least fill-factor. The results also shows that the drop in the fill-factor from the reference for the criss-cross grooves and the horizontal grooves orientations was about 3%, while that of the vertical grooves (VG) and the plain sheet was 8% and 12% respectively. The better results of fill-factor for the criss-cross grooves and the horizontal grooves can be attributed to the fact that, the orientation of the grooves in this manner provided evenly scattering of the solar flux on the module thereby reducing the hot spot formation and causing an even distribution of current within the solar cell . On the other hand, the reduced fill-factor for the plain sheet and the vertical grooves can be expalined in terms of the non-uniform irradiance leading to non even distribution of current within the solar cell. This causes hot-spot formation that leads to the overall degradation of the module.

3.3. Power comparison at 0° (normal)

Figure 4 shows the comparison of power at 0º with VG and NG giving the highest power output, but these are a result of high currents which cause hot spots and an overall reduction in the performance of the module. Hot-spot heating occurs when a large number of series connected cells cause a large reverse bias across the shaded cell, leading to large dissipation of power in the poor cell. Essentially the entire generating capacity of all the good cells is dissipated in the poor cell. The enormous power dissipation occurring in a small area results in local overheating, or "hot-spots", which in turn leads to destructive effects, such as cell or glass cracking, melting of solder or degradation of the solar cell[3].

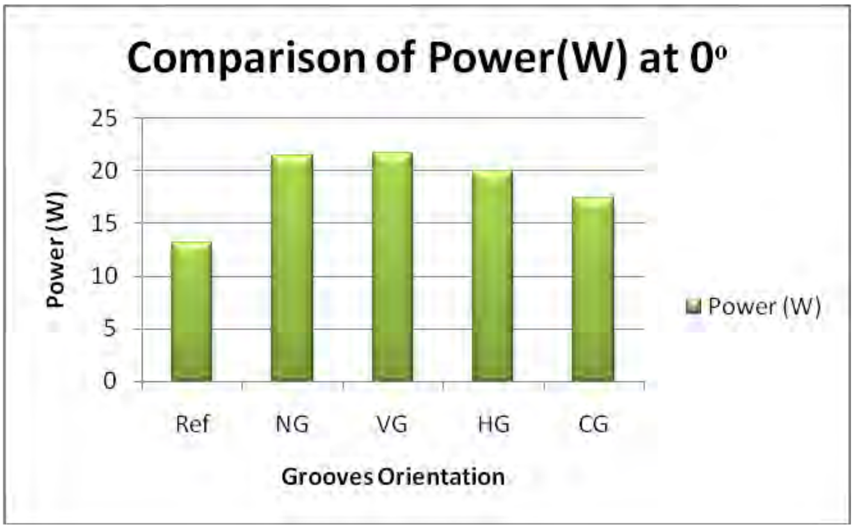


Fig. 4 bar charts showing comparison of the power for the four different grooves orientations and the reference (Ref) (without concentration).

4. Discussion and Conclusions

The performance of the CPC constructed using the locally available materials has been analysed and the results show that the locally purchased semi-diffuse aluminium structure can be used as a booster reflector in low cost photovoltaic system. The results also show that the criss-cross groove and the horizontal groove orientations were found to be the best orientations for the fill-factor improvement since they had only a 3% drop in fill-factor from the reference. The two orientations were able to scatter the solar flux evenly across the solar cell module. It is the even scattering that causes uniform distibution of currents within the solar cell thus reducing the hot spot formation. However, between the two orientations we would recommend the horizontal grooves(HG) because it is less costly when making the grooves but it gives a better fill-factor as much as that of the criss-cross grooves. The horizontal grooves also gave a higher power increase of 52% compared to 33% for the criss-cross grooves.

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