Design Comparison of Cassegrain Optic with without Secondary Optic for High Concentration Photovoltaic (HCPV)

[1]Nang Saw Yuzana Kyaing , [2]Nang Nung Lin
[1]Associate Professor, [2]Assistant Lecture
Electrical Power Engineering Department, Mandalay Technological University, Mandalay, Myanmar
Email - [1]nansawyuzana@gmail.com, [2]nandnunglin555

Abstract: *Design the cassegrain optic and flux intensity for high concentration photovoltaic (HCPV). In this design geometric concentration ratio is proposed to reduce the optical losses. To calculate the geometric concentration ratio, diameter of parabolic dish, hyperbolic dish, focal length and homogeniser length is 0.114m, 0.0228m, 0.0741m and 0.038m respectively. Multi-junction solar cell with a cell size of $0.02304\times10^{-3}m^2$ is used to design concentration ratio of 380X when air mass is 1.5.The available flux intensity on the cell area is proposed by using SolTrace. This paper compares the flux intensity of solar cell when cassegrain optics with secondary optic and secondary optic.*

Key Words: *Cassegrain Optic, Flux Density, Geometric Concentration ratio, Multi-junction Solar Cell, SolTrace*

1. INTRODUCTION:

Concentration photovoltaic (CPV) systems are made up of optical devices that focus light to decrease areas of photovoltaic (PV) material. As the result, the expensive PV material is replaced by more affordable mirrors and/or lenses, reducing the overall cost of the system but maintaining the area of energy captured and the efficiency at which it is converted. The two main advantages of concentrating photovoltaic (CPV) are ability to reduce system costs and to increase the efficiency limits of solar cells [6].

The main constraint in the success of CPV technology is heating cell which increases the temperature and thus the efficiency of the cell reduces. All CPV systems have a concentrating optic and a solar cell [1].

The concentration assembly consists of primary reflector as a parabolic dish and a secondary reflector as a hyperbolic mirror, arranged as a cassegrian arrangement [2].

The use of cassegrain concentrator increases the output power by four factors which reduce the Si material size which reduces the size of all system. Also one of the great advantages of cassegrain concentrator is increased the depth of focus of the system which simplifies the tracking system and reduces the total cost of solar energy system [3].

2. LITERATURE REVIEW:

Carlos Algora, Ignacio Rey-stolle, [8] observed that Multi-junction cells attached to the head spreader followed by a heat sink to dissipate heat and lower cell temperature, as cell performance decreases at higher temperature. A.Yavrian,S.Trembly,R.Gilbertand M.Levesque, [5] "How to increase the efficiency of a high concentrating PV (HCPV) by increasing the acceptance angle ± 3.2°" demonstrated acceptance angle was ± 3.2° for a geometric concentration ratio of 380 suns(380X). Katie Shanks, Nabin Sarmah, Juan P.Ferrer-Rodriguez et.al, [4] analyse the concentration of a system can be classed as low (<10 suns), medium (10-100 suns), high (100-2000 suns) and ultrahigh (>2000 suns) due to the different solar tracking requirement.

Katie Shanks, Nabin Sarmah, Juan P.Ferrer-Rodriguez et.al, [9] ascertained about the imaging optics, the goal is to create an image of the source on the target and non imaging optics key challenges are energy efficiency and specific distribution of light. Nabin Sarmah [7] III-V material have excellent optoelectronic properties to manufacture high efficiency solar cells. This paper use both of imaging and non-imaging optics. Therefore, triple junction cell GaInP/GaInAs/ Ge selected for apply in this research work.

3. METHOD:

For this proposed system, the following methology is considered step by step.

- Consider the arrangement of Mini Dish Cassegrin with and without secondary optic
- Calculation the desired design
- Simulation by SolTrace software
- Analyse the results

4. DESIGN CONSIDERATION FOR MINI DISH CASSEGRAIN WITH AND WITHOUT SECONDARY OPTIC:

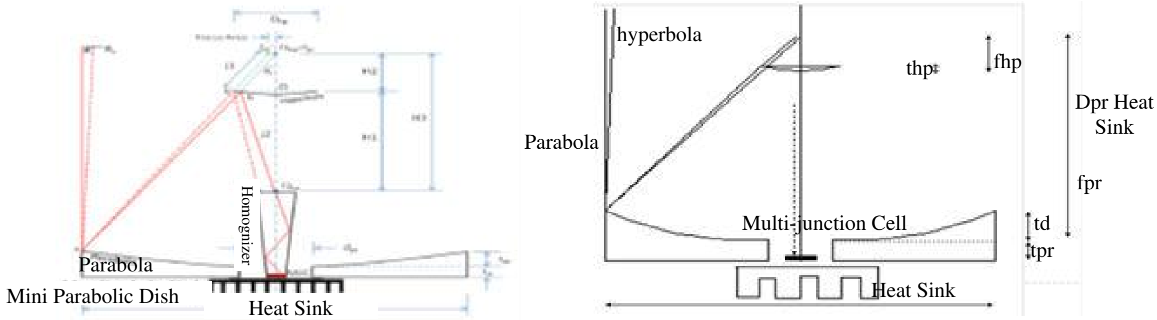


Figure.4 Mini Dish casssgrain with and without Secondary Optic

There are two types of concentration ratio (i) optical concentration ratio (ii) geometrical concentration ratio. The geometric concentration ratio (CR_g) is defined as the ratio of primary concentrator net area (A_{con}) to solar cell area (A_{cell}), is defined as the follow [8]:

$$CR_g = \frac{A_{con}}{A_{cell}} \quad (1)$$

The acceptance angle is defined as being the angular range over which all or most of the rays are accepted without moving the reflector, [8]:

$$CR_{ideal} = \frac{1}{\sin^2 \theta_a} \quad (2)$$

In turn, $\alpha_{equiv\ sun}$ results from adding the theoretical acceptance angle $\alpha_{acceptance}$ and the sun angular size α_{sun} is as follows [9]

$$\alpha_{equivsun} = \alpha_{sun} + \alpha_{accep\tan ce}$$
$$\alpha_{equivsun} = 0.265° + \alpha_{accep\tan ce} \quad (3)$$

Figure 4 shows detail parameter of primary and secondary concentrators and homogenizer and cell area.

The mini parabolic dish is based upon the simple equation of parabola given by [9]:

$$y = \frac{x^2}{4 f_{pr}} \quad (4)$$

where, $x = \frac{D_{pr}}{2}$, y (or) t_{pr} = the depth of parabolic , f_{pr} = focal length of parabolic,

D_{pr} = diameter of parabolic dish

The mini dish of rim angle θ_r is calculated as follows [9]

$$\theta_r = \tan^{-1}\left(\frac{D_{pr}/2}{f_{pr} - t_{pr}}\right) \quad (5)$$

To find the area of parabolic concentrator using equation (6)

$$A_{con} = \frac{2\pi}{3P}\left[\sqrt{\left(\frac{D_{pr}^2}{4} + P^2\right)^3} - P^3\right] \quad (6)$$

Where, $P = \frac{D_{pr}^2}{8 t_{pr}}$

Substituting equations (1), (4), (5) and (6), the area of parabolic concentrator (A_{con}) and geometric concentration ratio (CR_g) can be calculated.

The size of the secondary reflector is of great importance, which is designed according to the dimension of primary reflector. Hyperbolic reflector has two focal points, f_{1hp} and f_{2hp} [9]. To calculate the parameter of hyperbolic, the following equations are used

$$H_3 = f_{pr} + t_d - L - M_t \quad (7)$$

Where, L = length of homogenizer, M_t= thickness of multi-junction cell

As the rim angle of primary reflector θ_r is 42.09°, the parameter of j_1 and H_2 can be determined by [9]:

$$j_1 = \left(\frac{Ob/2}{\sin\theta_r} \right) \quad (8)$$

$$H_2 = \left(\frac{Ob/2}{\tan\theta_r} \right) \quad (9)$$

$$H_1 = H_3 - H_2 \quad (10)$$

By using Pythagoras theorem,

$$j_2 = \sqrt{H_1^2 + \left(\frac{Ob}{2}\right)^2} \quad (11)$$

To get the coordination hyperbolic reflector, the hyperbolic equation is used.

$$\frac{y^2}{a^2} - \frac{x^2}{b^2} = 1 \quad (12)$$

Equations (7) through (12) can be used to find the depth of secondary hyperbolic dish (t_{hp}).

5. DESING CALCULATION RESULTS:

Design calculation results give the geometric concentration ratio related with optical loss.

Table 5.1. PARAMETERS OF HOMOGENISER AND GASSEGRAIN

Symbol	Description	Conversion from Gaussain and CGS EMU to SI
M_t	Thickness of MJC	0.0005m
A_{cell}	Cell Size	0.0048 m×0.0048 m
D_{pr}	Diametere of first parabolic dish	0.114 m
f_{pr}	Focal length of first parabolic dish	0.0741 m
t_d	Thickness of first parabolic dish	0.01 m
d_{pr}	Center hole of size	0.0188 m
$\acute{O}b$, Ob	Diameter of first and second hyperbolic dish	0.0228 m, 0.0188 m

Table 5.2. RESULTS OF GEOMETRIC CONCENTRATION RATIO

Symbol	Description	Conversion from Gaussain and CGS EMU to SI
t_{pr}	depth of 1^{st} parabolic dish	0.010962 m
A_{con}	area of 1^{st} parabolic dish	0.010578 m²
θ_r	Rim Angle	42.09°
H_1, H_2, H_3	-	0.035593 m , 0.010407 m, 0.046 m
J_1, J_2	-	0.014024 m, 0.036813 m
a,b,c	-	0.011395 m, 0.020553 m, 0.0235 m
t_{hp}, A_{hp}	Depth and area of 2^{nd} hyperbolic dish	0.00187 m, 4.16×10^{-4}m²
A_{homo}	Area of homogenizer	$6.36173\times 10^{-5}\ m^2$
$A_{con} \div A_{hp}$	-	25.427
$A_{hp} \div A_{homo}$	-	6.5391
$A_{homo} \div A_{cell}$	-	2.76116
CR_g	Geometric concentration ratio	459.09X

According to this Table 5.2, the result of depth value and area of primary parabolic dish, depth value secondary hyperbolic dish, and geometry concentration ratio is 459.09X. Ray losses and optical losses are considered as 7%and 13% in this result based on the reference [5]. So the desired value of concentration ratio is obtained 380X. When Focal length is decrease, optical loss is increase. If the Optical loss is increased, average flux on the cell would be decreased.

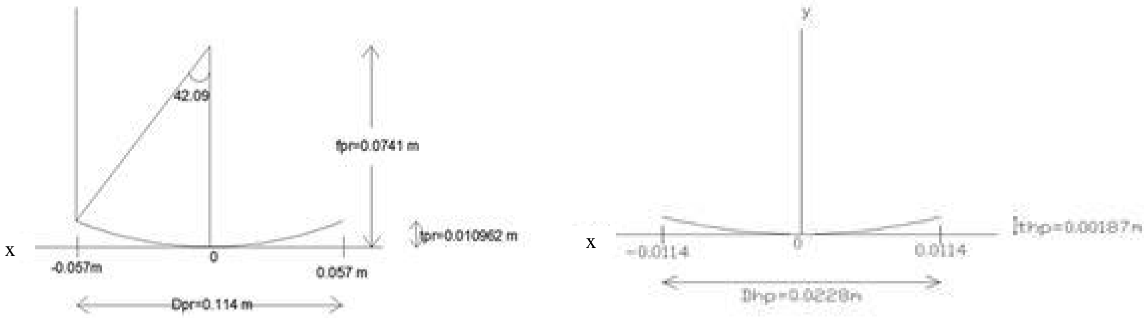


Figure 5. Mini Parabolic and Secondary Hyperbolic Dish Coordinate

The maximum value of x is half of diameter of mini dish and the value of y is the depth of parabola, given by the equation (4) for certain focal length. The coordinates of mini parabolic dish is 0.0228 m that are given in Figure 5. Figure 6 is described the value of depth of secondary hyperbolic dish.

6. SIMULATION RESULTS FOR RAYS INTERSECTION AND FLUX INTENSIY ON THE CELL:

SolTrace is a software tool developed at the National Renewable Laboratory (NREL) to model concentrating solar power optical systems and analysis their performance.

6.1 Simulation Result of Cassegrain Optic with Secondary Optic

The model consists of optical elements are three stages and one target. There are primary parabolic dish, secondary hyperbolic dish, homogenizer and target (multi-junction cell).

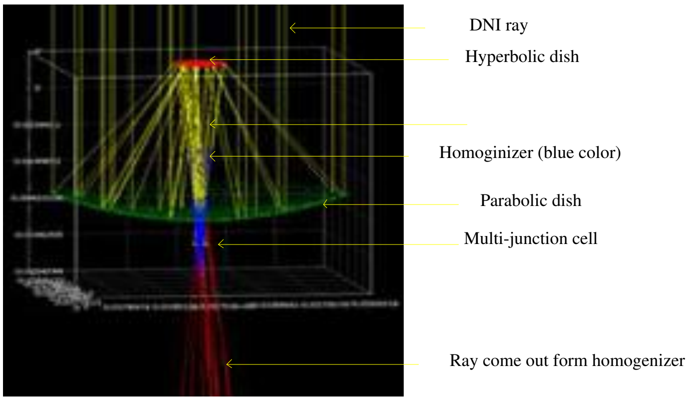
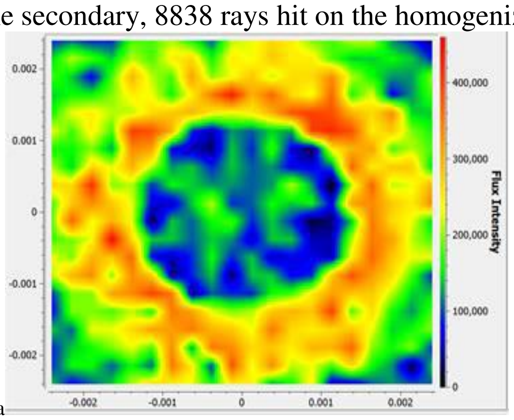


Figure.6.1 Ray Intersection of Cassegrain Design with Secondary Optic

In first stage, the parabolic dish aperture is 0.114m, the depth of dish is 0.010962m when focal length is 0.0741m. In second stage is hyperbolic dish aperture is 0.0228m, depth of dish is 0.00187m when f_{1hp} is 0.0741m and f_{2hp} is 0.028m. In third stage, area of homogenizer is 6.36173×10^{-5}. Final stage, Area of multi-junction cell is 2.304×10^{-5}m². All of the stages are built in SolTrace as shown in Fgure 6. The different stages have different colour. For the input data the direct normal irradiance (DNI) strike on the primary parabolic dish is 1000W/m² and the number of ray is 0-20 is considered.

From this figure, the scatter of ray intersections for four stage is described for focal length of primary parabolic dish is 0.0741m. A DNI is assumed 1000W/m² in this analysis. According to the result, the rays hit on the primary dish is 10000, 9598 rays hit on the secondary, 8838 rays hit on the homogenizer and 4551 rays hit on the cell.



cell area

Figure. 6.2 Contour Plot for Cassegrain with Secondary Optic Showing Flux on the Multi-junction Cell

In Figure 6.2, the result showed the peak flux is 459868W/m^2 and average flux is 201104W/m^2 on the cell. In this situation, those flux are depending on the desired cell area and dish area. For this simulation test, cell area and dish area are 0.0048m×0.0048m and 0.010578 m² respectively. Dish aperture and cell area do not change. If the focal length is changed, the depth of parabolic and hyperbolic dish would change. Ray losses, optical losses and flux intensity on the cell are depending on the focal length of both dishes.

6.2 Simulation Result of Cassegrain Optic without Secondary Optic

The model consists of optical elements are two stages and one target. There are primary parabolic dish, secondary hyperbolic dish and target(MJC).

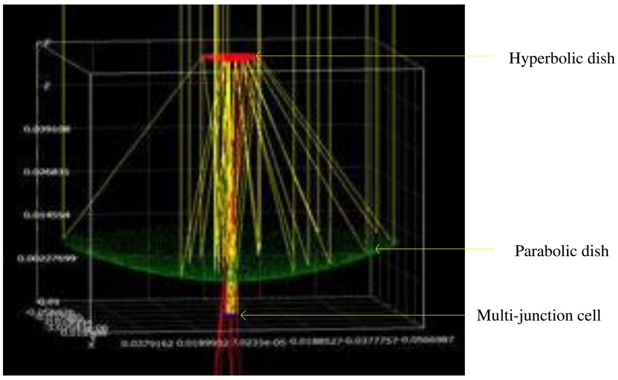


Figure. 6.2 Ray Intersection of Cassegrain Design without Secondary Optic

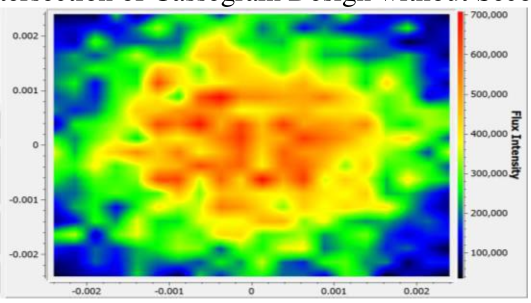


Figure. 6.3 Contour Plot for Cassegrain without Secondary Optic Showing Flux on the Multi-junction Cell

In Figure 6.3, the result showed the peak flux is 707666 W/m^2 and average flux is 304341W/m^2 on the cell. In this situation, those flux are depending on the desired cell area and dish area. For this simulation test, cell area and dish area are 0.0048m×0.0048m and 0.010578 m² respectively. Dish aperture, focal length and cell area do not change. If the secondary optics is not utilized in this design, the optical losses is decreased and then the value of flux intensity would be increased. From this two results, the inclusion of secondary optic is much more suitable for this proposed system.

7. CONCLUSION:

CPV system based on Cassegrain mini dish arrangement was developed and analyzed by using SolTrace. After anlalyse the results, the value of flux intensity in cassegrain optic with secondary optic or homogenizer was better increment by comparing cassegrain optic without secondary optic or homogenizer at the same DNI. According to the result of two different design, the cassegrain optic with secondary optic or homogenizer is more feasible than cassegrain optic without secondary optic or homogenizer. Because they achieved higher flux intensity on the multi-junction cell.

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