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Design and Comparative Analysis of CPV System For Performance Enhancement

Thierry Thomasse, Shankar Duraikannan, Jacqueline Lukose, VineshThiruchelvam
School of Engineering, Asia Pacific University of Technology and Innovation, Kuala Lumpur, Malaysia

Abstract

Solar power is a fascinating means of generating electricity. Owing its popularity thanks to photovoltaic panels in the last decade, solar power generation became widespread. PV panels however, remains quite inefficient. Concentrated photovoltaic systems (CPV) have proven to be more efficient than its predecessor. This paper aims to design a new CPV system implementing the latest technological advances. The new design is a multi-facet parabolic dish of radius 1.5m, with a focal length of 1.811m, consisting of 121 facets, concentrating sunlight towards a parabolic receiver. The flux concentration and light uniformity is then measured and compared to a benchmark design and a conventional parabolic dish.

The simulation results showed a 4.8% increase in output power. By comparing the simulation with a benchmark design presented by Zanganeh et al (2012), it is found that by using 5 junction MJ solar cells, approximately 2kW is generated with the final design. This solar generated power is able to provide two thirds of a conventional electrical house supply. The hotspot was spread out over an area of three times wider, by placing the parabolic receiver of radius 4mm, 10mm focal length, 20mm behind the multi-facet dish’s focal point.

Keywords: CPV System, Multi-facet Parabolic Dish, Parabolic Receiver, 5 Junction MJ solar cell, Tracepro.

Introduction

Solar power is the most popular renewable source of energy today (Berrer, 2014). With 85,000 TW of energy generated by the sun, only a fraction of this energy is required to supply the planet’s electrical needs. The aim is to gather this energy and convert the latter into electricity. One way is to use the solar power to heat water. The vapour produced activates a turbine which provides power. Another method, more conventional and more popular, is to make use of solar panels. This one is made of sophisticated semi-conductors able to convert sunlight into electricity directly. Despite its popularity, solar panels remain the least efficient means of producing electricity. A CPV System has the ability to concentrate sunlight towards a single spot reaching higher efficiency than most of the other solar power enabled systems. This paper is about the performance enhancement of a CPV system.

Design Configuration

To validate the results, the final design is compared with two other design configurations shown in Table 1. The benchmark design is from Zanganeh et al (2012).

Table 1: Comparison of the different design parameters

	Benchmark Design	**Conventional Parabolic Dish**	**Final Design**
Dish radius	1.5m	1.5m	1.5m
Focal length	3m	1.811m	1.811m
Number of facets	19	1	121
Rim angle	28˚	45˚	45˚
Number of curvatures	4	-	15

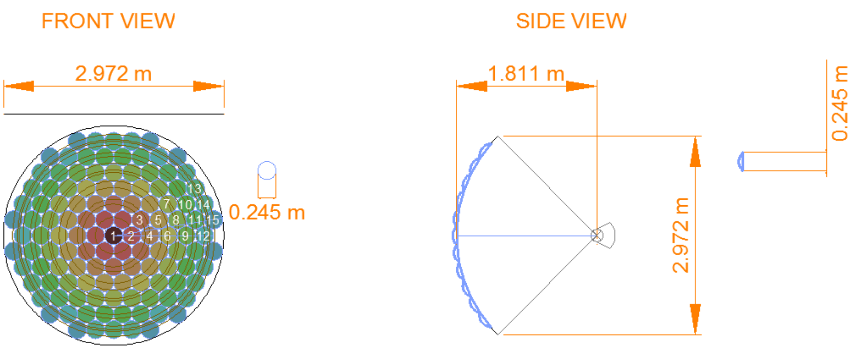

Figure 1: Dimensioning the multifaceted dish

Figure 1 shows the final design built on AutoCAD. The latter is used to calculate the values shown in Table 2. These values are used to locate each facet on Tracepro.

Table 2: Summary table of the facet type positions and angles

Facet type	Radial coordinate of facet centre point (m)	Azimuthal coordinate of facet centre point (°)	Slope of major axis (°)	Z (m)
1	0	0	0	0
2	0.245	0,60,120,180,240,300	3.869717076	0.00829
3	0.4244	30,90,150,210,270,330	6.683035116	0.02486
4	0.49	0,60,120,180,240,300	7.704448923	0.03314
5	0.6482	19,41,79,101,139,161,199,221,259,281,319,341	10.14635117	0.058
6	0.735	0,60,120,180,240,300	11.47107168	0.07458
7	0.8487	30,90,150,210,270,330	13.18751793	0.09943
8	0.8834	14,46,74,106,134,166,194,226,254,286,314,346	13.70674251	0.10773
9	0.98	0,60,120,180,240,300	15.13994339	0.13258
10	1.0679	23,37,83,97,143,157,203,217,263,277,323,337	16.42747293	0.15743
11	1.1227	11,49,71,109,131,169,191,229,251,289,311,349	17.22170434	0.174
12	1.225	0,60,120,180,240,300	18.68609901	0.20715
13	1.2731	30,90,150,210,270,330	19.36611028	0.22374
14	1.2964	19,41,79,101,139,161,199,221,259,281,319,341	19.6934973	0.23201
15	1.3641	9,51,69,111,129,171,189,231,249,291,309,351	20.63713317	0.25687

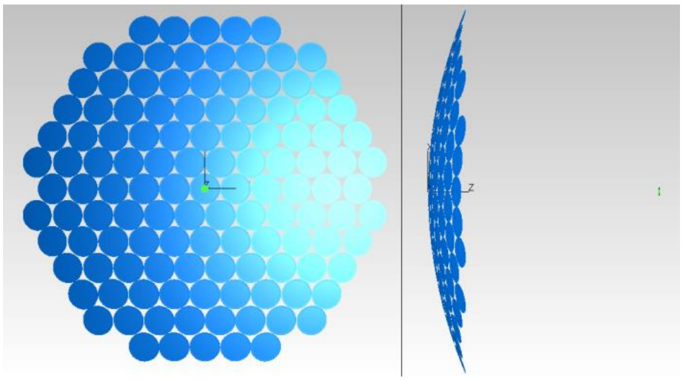

Figure 2: Final design implementation on Tracepro

Simulation Results

The final design dish is built on Tracepro and the source parameters are set; the wavelength is set to 0.5µm (solar peak wavelength) and the irradiance is set to 4000 w/m^2. Tracepro simulates 118701 rays in a circular pattern over an area of 3.2375m^2 towards the multi-facet parabolic dish.

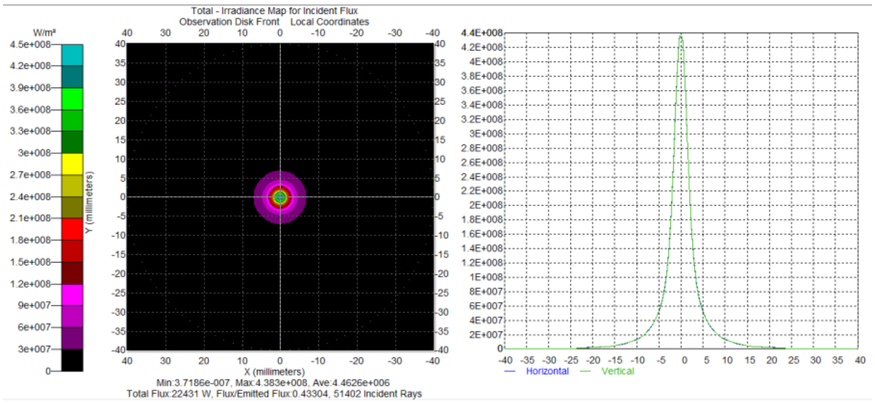

Figure 3: Final design dish of 1.5m radius, 1.811m focal point, consisting of 121 facets of 0.11m radius simulated at 250 rings

Figure 3 shows the reflection of the 121 facets on a single spot. The light concentration at this point is very high, reaching a peak value of 0.44 GW/m^2. The detector received 51,402 incident rays for a total flux of 22.4 kW over a surface of 50.3 cm^2. The ratio of the flux on the receiver to the total flux emitted is of 0.433. Considering that the source grid is larger than dish diameter by 25 to 35cm, the intercept ratio is correct. Indeed, more than 40% of the rays emitted by the source were intercepted and reflected on the receiver. Hence if the grid source was smaller the ratio would increase.

Experimental Setup

Two experiments are undertaken to compare the results of the final design; one from the benchmark paper and the second from a conventional parabolic dish. The comparison is in terms of the total flux (W/m^2), number of incident rays and ratio of the received flux to emitted flux. Once the comparison of the 3 designs are done, the final design is assessed again by modifying the receiver's distance and shape (hotspot correction).

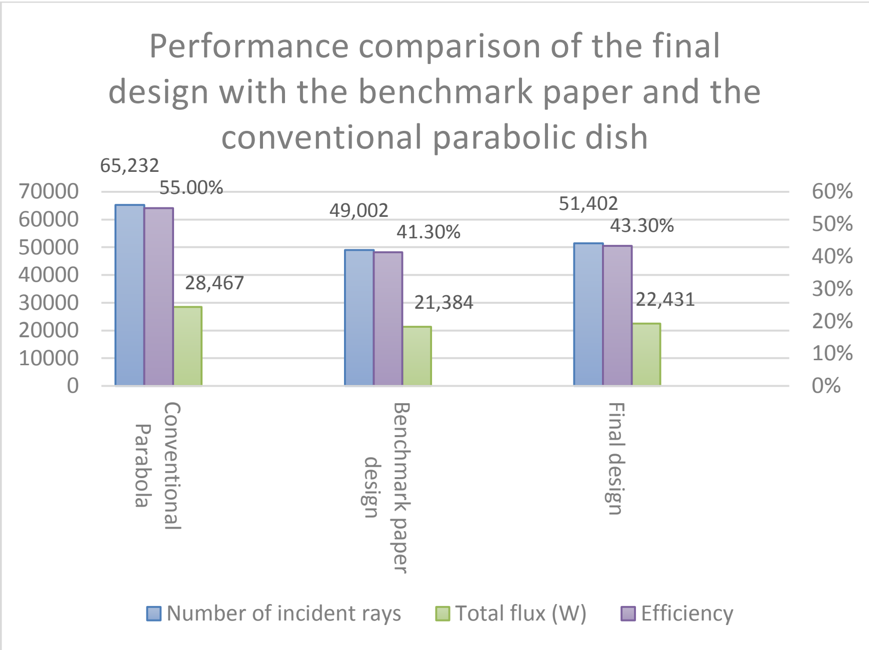

Figure 4: Comparison of the three designs with respect to the number of incident rays, total flux and efficiency

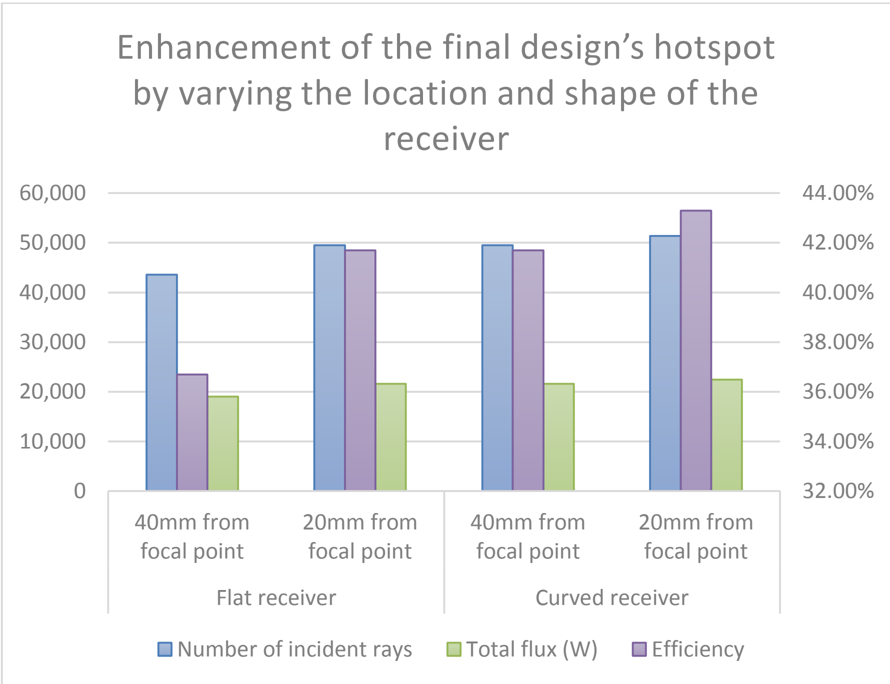

Figure 5: Hotspot improvement of the final design by varying the focal length and shape of the receiver

Conclusion

In this paper, a multi-facet dish of radius 1.5m, consisting of 121 facets and a focal length of 1.811m, is designed. This final design is compared with a benchmark one of same size, consisting of 19 facets and a focal length of 3m and a conventional dish of a single parabolic mirror of the same size, with a focal length of 1.811m. Since the parabolic dish was proven to be impractical and very expensive, the final design was only compared to the benchmark design. Therefore keeping the results of the conventional parabolic dish as a reference.

The final design results showed a 4.8% increase in the output power by using 5 junction MJ cells. Moreover, the hotspot size was tripled, thus covering a wider surface area on the receiver. This allows the light rays to be uniformly spread over the MJ cells. Therefore the current mismatch due to non-uniform illumination is decreased. Further research could be done by using a range of wavelengths instead of the sun's peak wavelength. A larger dish could be simulated to determine the minimum dish size to fully supply the electrical needs of a conventional house. In addition, temperature could be assessed in further research to measure the impact on the performance of a small CPV system of this size.

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