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Design and simulation of a large-scale telescopic paraboloidal solar concentrator: Dual receiver

Barena Bekalo Betela*[1] Venkata Ramayya Ancha[1] and Lingala Syam Sundar[2]

[1]Faculty of Mechanical Engineering, Jimma University, Jimma, Ethiopia

[2]Mechanical Engineering, College of Engineering, Prince Mohammad Bin Fahd University, Al-Khober, Saudi Arabia

* newyr29@yahoo.com

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Abstract. Beam-down solar concentrators with a secondary reflector are receiving a lot of attention at present. Large telescopic dual-receiver solar concentrators with Gregorian and Cassegrain alignments have been modelled and investigated in the present study with each telescopic design having a unique set of receivers that are mounted and anchored to the ground. A comparative assessment of both of the telescopic alignments have been carried out along with minimum image radii The results reveal that both telescopic designs are capable of splitting incoming sunlight and facilitating the use of two receivers. For the design and simulation of telescopic designs, Tonatiuh and Soltrace have been employed for a comparative evaluation. Both of the conventional and telescopic designs using Soltrace and Cassegrain, as well as conventional designs by Tonatiuh, produced identical results in the simulation of total power on the receiver, However, a sizable peak flux discrepancy was seen between the results from Tonatiuh and Soltrace.

Introduction

Overhead positioning of a large heat receiver of the tower, strilling engine, and furnace has difficulties during operation, maintenance, and construction. Heat is lost during the transfer procedure because the receiver location on the tower requires a lot of energy to push up. To solve this issue, research is being done on a beam-down system with a ground-fixed receiver [1].

Beam-down concentrating solar technologies supply useful heat for extremely efficient power cycles and direct solar fuels with receiver reactor technology at high temperatures. Because of the high-temperature heat production and chemical reactions occur on the ground rather than at a great height, the system is safer [2-12][7, 13, 14]. A secondary reflector is a tool for beam-down technologies. Solar collector with a secondary reflector is the fastest-growing technology [15-25]. One of the solar thermal energy technologies with a secondary reflector is a parabolic dish [26-29].

Using secondary reflectors in parabolic dish design is highly related to the design of Gregorian and Cassegrain telescopes because these telescopes are a two-mirror system [30]. Designing and aberration correction are the main works during designing telescopes [31-33]. Applying a telescopic design for a parabolic dish may be used to increase the concentration ratio and then reduce optical and thermal losses and increase collector efficiency by correcting aberration. Optical aberration prevents the conventional parabolic dish from achieving the 46,000 geometric concentration ratio that is thermodynamically feasible. Due to the aberration, only a maximum of 11,000 is obtained with a 1.0 intercept factor [26]. This shows that optical aberration is the main problem of the solar thermal technology. Therefore, an optical aberration decreases the geometric concentration ratio, increases re-radiation and other optical losses, and decreases collector efficiency. One of the important issues in telescopic design is the control of optical aberration [34-37].

There are no studies reported so far, to use telescopes for solar thermal energy technology and correcting optical aberration during design of a conventional parabolic dish. Additionally, current research does not consider sunlight blockage by secondary reflectors. This study proposes consideration of light blockage by secondaryreflectors as an opportunity for the division of incoming sunlight into two approximately equal parts. Utilization of solar energy requires multi-operation such as during daytime and nighttime. Dividing the receiver into two parts will help to reduce the challenges related to a single receiver. Moreover, there is a research gap noticed to use beam-down and beam-up solar collection simultaneously.

Therefore, paraxial ray tracing-based research was carried out in this study on the parabolic dish.The study is based on the design principle of the Gregorian and Cassegrain telescopes (two-mirror optics) and named telescopic paraboloidal solar concentrator. The main advantage of this new concept is: (i) to reduce the receiver load of the conventional parabolic dish by dividing it into two receivers;(ii) to place some challenging receiver configuration such as concentrated photovoltaics on the ground;(iii) to make telescopes to function both as solar thermal energy technology and telescope. Therefore, the tertiary reflector was added to a Gregorian telescope, whilefront and back sides simultaneous reflecting secondary reflector was added to Cassegrain telescope without disturbing the existing telescopes operations.

Methodology

Large-scale design of Gregorian and Cassegrain telescopic dual receiver system

A large-scale Gregorian and Cassegrain telescopic dual receiver paraboloidal solar concentrators were designed by paraxial ray tracing (Gaussian optics) method. Then the system was modeled and simulated by Monte Carlo ray tracing Tonatiuh, Tonatiuh-Mathematical combination and Soltrace software. The telescopes' existing design was modified to make it a solar thermal energy technology. Consequently, tertiary parabolic reflector was added to Gregory telescope, while the secondary in Cassegrain telescope was made with front and back sides simultaneously reflecting. Secondary and tertiary reflectors had the same diameter and opposite in direction. i.e., secondary views primary concavely and tertiary set up as conventional parabolic dish or were made back-to-back connected.

Axial obscuration ratio and f-Number selected were 0.5 and 1.8 respectively. Firstly, Gregory telescopc was designed and then the Cassegrain telescopic was designed depending upon Gregorian design. As indicated in Table 1, Cassegrain was designed by converting Gregorian telescopic by removing tertiary reflector from Gregory and reducing the distance between the two concave mirrors in Gregory by half.

Table 1: large-scale dimensions of Gregorian and Cassegrain telescopic dual receiver paraboloidal solar concentrator.

	Gregorian design			Cassegrain design		
	Diameter(m)	Focal length(m)	Distance between mirrors(m)	Diameter(m)	Focal length(m)	Distance between Mirrors(m)
Primary reflector	30	54		30		
Secondary reflector	21.21	20.4414	81	21.21	20.4414	40.5
Tertiary reflector	21.21	20.4414	81	-	-	-

Results and discussion

Gregorian telescopic paraboloidal dual receiver solar concentrator

This study was performed by considering light blockage by secondary reflectors as an opportunity for dual receiver solar thermal energy technology design.

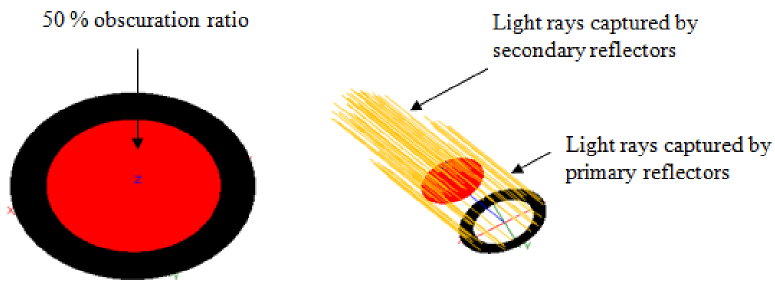

Figure 1: *Secondary reflector blocking the sun light, as drawn by Soltrace*

As Figure 1 indicates 29,994,611 light rays from 60 million released rays were captured secondary reflectorwhileprimary reflector captured 30,005,389 rays. Therefore, incoming rays were divided into two equal parts with axial obscuration ratio of 0.5.

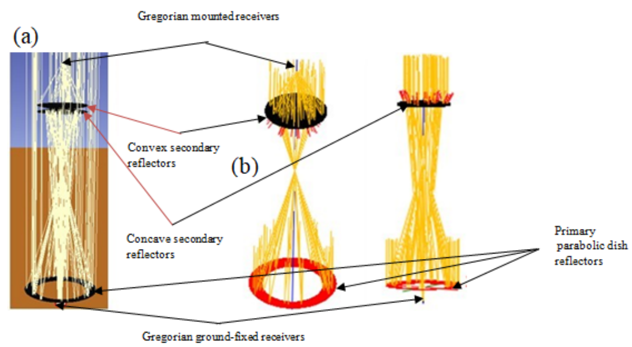

Figure 2: *Gregorian telescopic paraboloidal solar concentrator with mounted and ground-fixed receiver: (a) ray graphics in Tonatiuh software and (b) ray graphics in Soltrace.*

According to *Figure 2*above in Gregorian design, back-to-back connected secondary and tertiary parabolic dish reflectors were used to divide incoming sunlight to mounted and ground-fixed receivers in Tonatiuh. In soltrace separate modeling was made for secondary and tertiary reflectors.

Cassegrain telescopic paraboloidal dual receiver solar concentrator

As shown in Figure 3, the Cassegrain telescope design was modified by making secondary reflector to reflect at both back and front sides simultaneously.

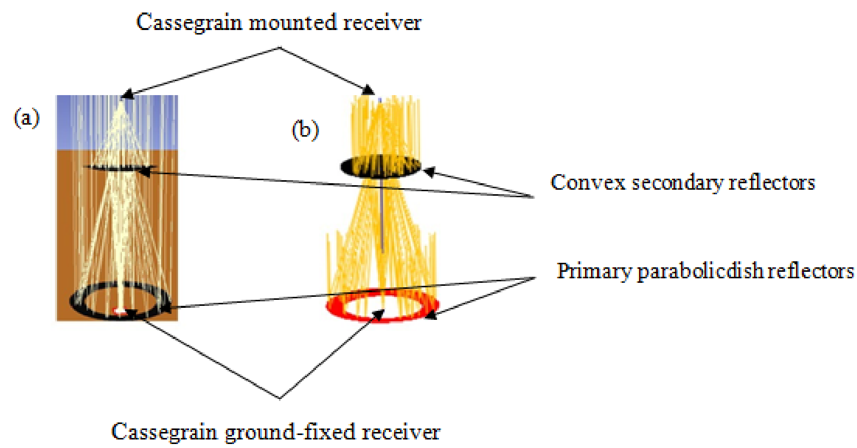

Figure 3: *Cassegrain telescopic paraboloidal solar concentrator with mounted and ground-fixed receiver: (a) ray graphics in Tonatiuh software and (b) ray graphics in Soltrace.*

As shown in *Table 3 in case of Tonatiuh, a* 30-meter diameter and 54-meter focal length parabolic dish has a total power of 706.354 kW, which is slightly greater (weak convergency or accuracy) than from the sum of the total power of the Cassegrain design and significantly different from the sum of the total power of the Gregorian design. Therefore, telescopic designs are better than conventional designs. According to Table 5 the sum of errors in the Gregorian design is 0.00104877818, which is smaller than the errors in the Cassegrain and conventional designs. Therefore, the smallest error observed in Gregorian design when comparing with the errors of Cassegrain and conventional designs indicates that Gregorian design is more accurate.

During sunshape simulation, as the distance from the primary mirror to the receiver increases, the accuracy increases. This is confirmed by the optical tool verification study of Wang et al.[38]. According to the authors, as the distance increase between the primary mirror and the target, the radiance distribution will be extremely similar to the corresponding statistical distribution of the slope error or sunshape. Therefore, Gregorian telescopic designs show better convergence than conventional and Cassegrain designs.

As indicated in Table 2, the sum of total power in case of Soltrace is equal in Gregorian and Cassegrain designs. In two cases it is 706.819kW.

Table 2: total power and peak flux Gregorian and Cassegrain telescopic paraboloidal solar concentrator

	Gregorian telescopic						Cassegrain telescopic					
	Mounted receiver			Ground-fixed receiver			Mounted receiver			Ground-fixed receiver		
	Tonatiuh	Tonatiuh-mathematica	soltrace	Tonatiuh	Tonatiuh Mathematica	soltrace	Tonatiuh	Tonatiuh Mathematica	Soltrace	Tonatiuh	Tonatiuh Mathematica	Soltrace
Total ower(kW)	335.199	331.625	353.346	339.383	339.424	353.473	352.449	352.456	353.346	350.951	353.474	353.473
Peak flux(Kw/m2)	5020.55	-	22,254,000,000	68.0677	-	3811.23	1934.11	-	22,254,000,000	740.605	-	3112410

Table 3: Tonatiuh's total power and peak flux of telescopic and conventional paraboloidal solar concentrators

	Gregorian design			Cassegrain design			Conventional design
	Mounted receiver	Ground-fixed receiver	added total power	Mounted receiver	Ground-fixed	Added total power	Receiver
Total power(kW)	335.199	339.383	674.582	352,449	350.951	703.4	706.354
Peak flux(kW/m^2)	1.0382*10^7	170.514	-	1.09102*10^7	173.725	-	3.44605*10^6

As *Table 4* describes, the simulation of conventional design gave 706.861kW. Therefore, there is no total power difference between conventional and telescopic designs by soltrace simulation.

Table 4: Total power and peak flux on the receiver of 30-meter diameter conventional parabolic dish

	Tonatiuh	Tonatiuh-Mathematica	Soltrace
Total power(kW)	706.354	706.332	706.861
Peak flux(kW/m^2)	3,444.95	-	1,569,190,000

Table 5: Errors of telescopic design

Gregorian design			Cassegrain design		
Tonatiuh error			Tonatiuh error		
Mounted receiver	Ground-fixed receiver	Sum of error	Mounted receiver	Ground-fixed reciever	Sum of error
0.000093384	0.00095539	0.0010487781	0.000256412	0.000112354	0.00036887

Generally, the simulation by Tonatiuh was very fast. It required 11 minutes to trace 60 million, while Soltrace used 2 hours for single run. Better convergence was obtained in case of Gregorian design by Tonatiuh. Minimum sun image radius was easily and clearly obtained by Tonatiuh-Mathematica combination.

To get total power and peak flux on receivers for comparison, modeling and simulation of a parabolic dish with a 30-meter diameter and 54-meter focal length were carried out. As previously indicated, all designs have nearly identical residual total powers, with the exception of the Gregorian design. However, a significant variation was seen in each case for the peak flux. The truth is closely akin to the study of [39] in that there was basically no difference between the Soltrace and the Tonatiuh estimates in terms of the solar total power influencing the target or the reception tube.

Conclusion

Designing Gregorian and Cassegrain telescopic dual receiver paraboloidal solar concentrators allows for the simultaneous usage of beam-down and beam-up sun beams. Both telescoping systems can produce two receivers by dividing the incoming light. The new design used the chance to be built ground-fixed and mounted receivers in both telescopic forms as a result of sunlight being blocked by secondary reflectors in beam-down concentrators. In order to avoid interfering with a Gregorian telescope's current operations, a tertiary reflector was added. While Cassegrain's existing functions are unaffected by simultaneous back and front side reflections. Reflecting telescopes can serve so as solar thermal energy technologies in addition to telescopes.

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Declaration of interest statement
The authors affirm that they have no known financial or interpersonal conflicts that would have appeared to have an impact on the research presented in this study.

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