Simulation and Evaluation of Small Scale Solar Power Tower Performance under Malaysia Weather Conditions

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Simulation and evaluation of small scale solar power tower performance under Malaysia weather conditions

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Abstract. Solar energy is the most available, clean, and inexpensive source of energy among the other renewable sources of energy. Malaysia is an encouraging location for the development of solar energy systems due to abundant sunshine (10 hours daily with average solar energy received between 1400 and 1900 kWh/m^2). In this paper the design of heliostat field of 3 dual-axis heliostat units located in Ipoh, Malaysia is introduced. A mathematical model was developed to estimate the sun position and calculate the cosine losses in the field. The study includes calculating the incident solar power to a fixed target on the tower by analysing the tower height and ground distance between the heliostat and the tower base. The cosine efficiency was found for each heliostat according to the sun movement. TRNSYS software was used to simulate the cosine efficiencies and field hourly incident solar power input to the fixed target. The results show the heliostat field parameters and the total incident solar input to the receiver.

1. Introduction

All Solar Power Tower (SPT) systems are just commercially employed in certain regions in the world especially in arid areas of mid-latitude zones, such as Spain, Russia, Italy, Germany, Australia, and US [1]. It is usually believed that SPT systems cannot be used in the tropics with relatively high diffuse fraction of global radiation. However, there is no systematic study on this issue [2].

Malaysia is rapidly developing and the growing energy demand requires alternative energy sources to fulfil the demands [3]. Currently most of the solar power used in Malaysia is Photovoltaic (PV) systems on a domestic level only and large scale commercial use is not significant yet [4].

In this paper the solar power tower technology is examined for collecting and redirecting solar power in order to produce thermal energy for latitude 4.34° in Malaysia by designing a small-scale heliostat field then calculating the cosine efficiency for each heliostat and finally simulating the incident solar input to a fixed target mounted on the top of a tower.

2. Model description

2.1. Sun position definition

In order to calculate the hourly heliostat field efficiency, a model for solar position has been utilized. The solar position equations are obtained from Duffie and Beckman [5].

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2.2. Heliostat field layout design

Radial staggered layout is the best layout for solar power plants due to its reduced blocking and shadowing losses [6]. The heliostat placement is implemented with the tower centre as the origin using the radial and azimuthal spacing formulas.

2.3. Tower calculations

Several useful mathematical relationships can be obtained from figure 1. These relationships are important in determining the target λ and facing angle $\emptyset$ for each heliostat.

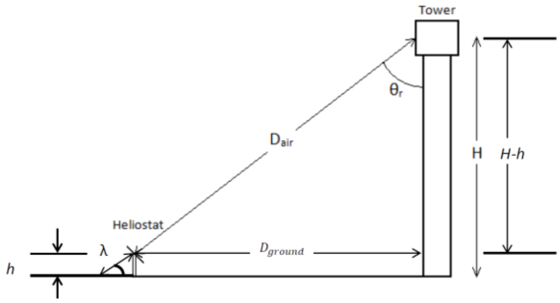

Figure 1. Tower and Heliostat trigonometry relationships.

2.4. Field solar input

The total solar radiation input on the field $Q'_{Solar-total}$ is calculated as in (1):

$$Q'_{Solar-total} = I_{bn} \times A_{total} \tag{1}$$

Where I_{bn} is the direct beam irradiance and A_{total} is the total reflective area of the heliostats.

2.5. Incident solar power on the target

The incident solar power to receiver $Q'_{inc-rec.}$ is calculated by [7] as in (2),

$$Q'_{inc-rec.} = Q'_{Solar-total} \times \eta_{field} \tag{2}$$

Where η_{field} is the field losses.

2.6. Field losses

Heliostat Fields encounter numerous losses, which are referred as field losses. These field losses η_{field} can be calculated as follow [6]:

$$\eta_{field} = \eta_{cosine} \times \eta_{blocking\,\&\,Shadowing} \times \eta_{ref.} \times \eta_{tarcking} \tag{3}$$

Where η_{cosine} is the cosine effect, $\eta_{blocking\,\&\,Shadowing}$ is the blocking and shadowing efficiencies, $\eta_{ref.}$ is the reflective efficiency of heliostat mirror, and $\eta_{tarcking}$ is the tracking efficiency of the heliostat tracking system.

2.6.1. Cosine efficiency

Cosine efficiency has the greatest impact on solar power reflected by heliostat because it depends on the sun position and heliostat location [6]. Cosine efficiency is calculated according to:

$$\eta_{cosine} = \cos(\theta_i) \tag{4}$$

In this study, the average cosine efficiency for a single day (from 9 am to 4 pm) is calculated based on the Azimuth-Elevation (AE) tracking method. The angle of incidence θ_i has been calculated based on the target angle λ , facing angle $\emptyset$, solar elevation angle α_s, and solar azimuth angle γ_s as s [8].

Due to the small number of heliostats, blocking and shadowing efficiency were given the value of 1. The study assumes the use of Sun Tracer™ Dual-Axis Heliostat has a tracking error < 0.1° and 88% reflective efficiency.

3. Analysis

3.1. Heliostat field layout design

Spread-sheet calculations were implemented based on the mathematical model developed in the aforementioned section to determine the field layout. Using the data obtained from the spread-sheet calculations, a simple radial staggered field layout can be plotted as shown in figure 2.

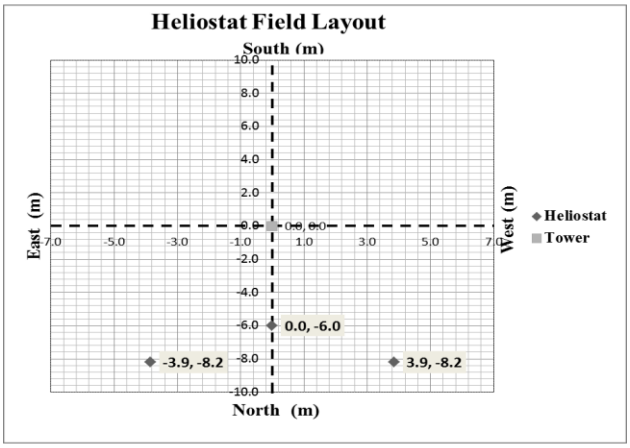

Figure 2. Final Field Layout for the 3 heliostat units.

3.2. Heliostat field modeling with TRNSYS

A TRNSYS model for the proposed heliostat field inputs and parameters has been developed to calculate the incident power to the receiver. All parameters and inputs are inserted according to the data obtained from the spread-sheet calculations for heliostat positioning and field efficiency.

4. Results and discussion

The 3 units of heliostats have been evaluated in terms of cosine efficiency and power incident to receiver as shown in figure 3 and 4. TRNSYS simulation had been carried out for the 3 heliostat units that are located in different positions from the tower as discussed in the previous sections.

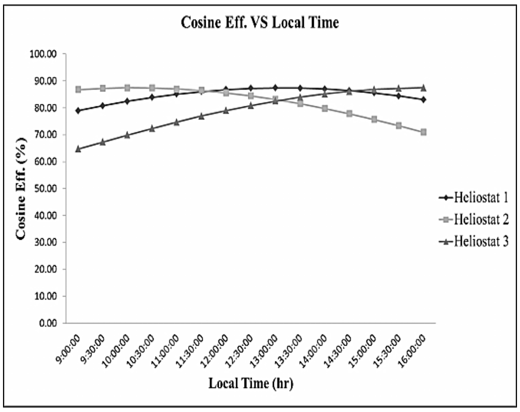

Figure 3. Cosine efficiency for heliostat 1, heliostat 2, and heliostat 3 at September 23.

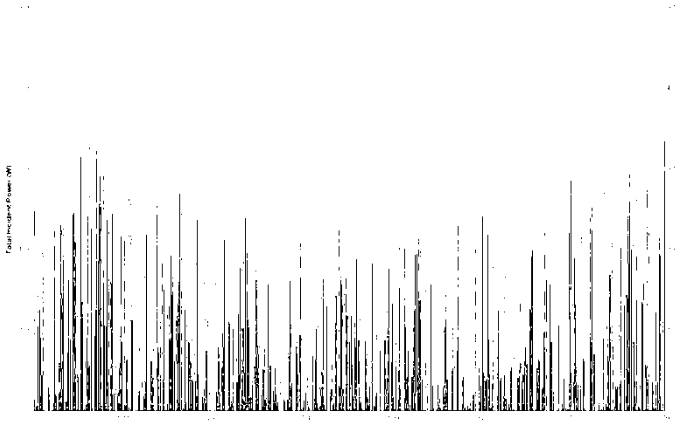

Figure 4. Total incident solar power to receiver from all heliostats throughout the year.

5. Conclusion

The heliostat field design for 3 units of dual-axis heliostat has been carried out, and the incident solar power input to receiver has been simulated for Ipoh, Malaysia. This preliminary layout and specifications shall be used to build a small-scale testing facility for solar power tower evaluation; thus TRNSYS simulations are required to determine the power rating for receiver sizing as next step. The heliostat field parameters were established in this study as shown in table1.

Table 1. Heliostat field parameters.

Heliostat Parameters							
No. of heliostats	Area of single heliostat	Width of heliostat	Length of heliostat	Height of heliostat	Radial spacing	Azimuthal spacing	Height of the tower
3	3.1 m^2	1.65 m	1.9 m	1.5 m	4.4 m	7.7 m	6 m

Heliostat positions						
Heliostat no.	Coordinates (m)			Ground distance from the tower (m)	Facing angle (degree)	Target angle (degree)
	X	Y	Z			
Heliostat 1 coordinates	0	-6	1.5	6	0	37
Heliostat 2 coordinates	3.9	-8.2	1.5	9.1	25.2	26.4
Heliostat 3 coordinates	-3.9	-8.2	1.5	9.1	-25.2	26.4

From TRNSYS simulation, the heliostat field delivers 7.5 kW as a peak value in day 361 (December 27) at solar noon. This amount of power can be increased by increasing the total reflective area of the heliostat field.

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