



## DUAL AXIS TRACKING MODEL FOR A HELIOSTAT FIELD SOLAR TOWER HEAT FLUX INVESTIGATION

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### ABSTRACT

The heat flux density and distribution are the main dominant design parameters for the solar tower plant output power and receiver formation. Beside the plant geometries of the tower height, heliostat dimensions, field layout, and the optical properties, the quality of these two values depends on the heliostat field efficiency, which outlined in the mirror tilt angle cosine effect, reflected rays' spillage loss, heliostat distribution blocking and shadowing and tracking control error. To investigate the annual heat flux collecting quantity and distribution for an experimental field, distributed and located in Universiti Teknologi Petronas, a detailed dual axis tracking model is elaborated herein.

**Keywords:** heliostat field; solar concentration technology; solar power tower.

### INTRODUCTION

Solar power tower plant technology utilizes the concentration of solar radiation to produce thermal energy. The main components of the system are the collector, receiver and power generation parts. The collector is composed of heliostat field and tower. The heliostat field is essential subsystem because it contributes 50% to the total cost and causes power losses by 40%[1]. In the literature, the heliostat field layout optimization is estimated by using special codes such as DELSOL3, WinDELSOL1.0, SOLTRACE, which have been developed for this purpose. The field optical efficiency is consisted of the reflection efficiency, the cosine efficiency, the interception efficiency, the blocking and shadowing efficiency and the atmospheric transmission efficiency. The configuration of heliostat field layout is usually determined by the field arrangement type, distance between heliostats, distance between rows, tower height and the receiver aperture. A new method for the design of the heliostat field layout for solar tower power plant is proposed by Xiudong Wei *et al* [1] their study is based on the MATLAB tools and validated by using current PS10 plant field. Another study is done by Zhihao Yao *et al* [2] where the modeling and simulation of DAHN solar plant is presented using a HFLD method for the field efficiency calculation. In these types of plants, the dual tracking technology is used to follow the sun daily and seasonal movement. For a percentage of error associated with the process of tracking L. A. Diaz-Felix *et al* [3] elaborate the instance angular offset in the tracking mechanisms. Imperfect leveling of the heliostat carrier, lack of perpendicularity between the tracking axes and the lack of precise clock synchronization, all these errors are considered in the installation of the field. Xiudong Wei *et al* [4] develop a new code for the design and analysis of the heliostat field layout for power tower system, the edge ray principle of no imaging optics is used in this code, a higher efficiency and faster optimization response speed are obtained according to their study. Another ray tracing tools are suggested by Belhomme *et al* [5] at the German Aerospace Center, the developed software is used to

simulate the flux density of heliostat fields with high accuracy in short period of computation time. Review of the principle and sun-tracking methods for maximizing solar systems output is presented by Hossein Mousazadeh *et al* [6] they described the different types of sun-tracking systems, and the cons and pros of the described methods are discussed. Francisco J *et al*. [7] investigate the main problems of heliostats fields design and optimization, a process of the recalculation of the shadings and blockings for each heliostat in the field at every stage of the optimization is dialed by generating new code called *campo*.

The objectives of this study are to investigate the receiver heat flux density and distribution for UTP experimental solar power tower plant. Using a dual axis tracking heliostat model and utilizing the optimum suggested no blocking heliostat field and space. And to determine the daily and seasonal tracking collection efficiency using ray tracing method depending on the reflected image size.

### FIELD LAYOUT PARAMETERS

To determine the amount of solar radiation heat flux density collected from the heliostats field and received at the top of the tower, a dual axis ray tracing model is done, and the image size formed by each heliostat is determined. Registered solar data are analyzed, and the radiation profile for most listed days in the solar data files is observed as follows. The least effected amount of 350 (w/m<sup>2</sup>) starts to appear at a time from 9:00 a clock AM to 7:00 a clock PM. For this time duration (9 hours per day), optimum heliostat inclination angle that could reflect the maximum collected radiation to the vertical stand target point and associated optical losses are estimated, based on central rays inclination.

The solar field global coordinates are 4° latitude, 100° longitude at Universiti Teknologi Petronas. The total number of mirrors in the field is 12 units. The installed field layout is depicted in Figure-1. This layout is distributed in three rows, the first row is marked with the number of 1 and the second row is marked with 2, and 3



for the third row. The heliostats located in the east takes the E letter and that in the west takes the W letter, when the middle heliostat takes M letter. The first row distance from the tower is 10.25 meter measured from the center of the heliostat, and the distance between rows is 5 meter, the height of the center of the receiver is 9.5 meter, and the height of the heliostat is 1.5 meter from the ground. The heliostats dimensions are (2.5m length – 1.5 m width) with 3.75m<sup>2</sup> aperture area. The total heliostat area is 45m<sup>2</sup> filling a field of 484 m<sup>2</sup> land space.

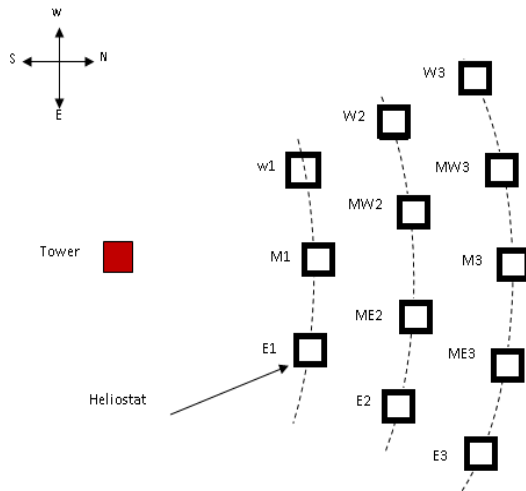


Figure-1. Suggested field layout.

### DUAL AXIS TRACKING MODEL

For the suggested field layout, two types of heliostat tracking movement are elaborated. The first is for the hourly tracking of the sun, from east to west, this tracking mode affects the image width. The second trace the seasonal tracking of the sun, when the sun is traveling from the line of 23°, 26' south (Tropic of Capricorn) to the line of 23°, 26' North (Tropic of Cancer) through the year, this tracking affects the image length. For these two types of movement each heliostat is equipped with two motor, motor (A) for the hourly tracking and motor (B) for the seasonal tracking. Concerning the seasonal tracking angle, table (1- left) represents the monthly solar declination angle in the suggested global coordinates, according to the solar angle calculator. And to follow the sun hourly movement, from the period of 9:00 Am to 7:00 Pm, and that's because of the observed effective solar radiation in the registered data at this limit of time. For this mentioned period of time the sun hourly incident angle is tabulated in table (1-right). The angle in right side of Table-1 is estimated values for the purpose of general tracking model design.

Table-1. (left) Monthly solar incident angle (Right) the hourly sun incident angle.

Month	Angle °	hour	Sun Angle °
Dec	62	8.00 AM	15
Jan	69	9.00 AM	30
Feb	77	10.00 AM	45
Mar	85	11.00 AM	60
Apr	93	12.00 AM	75
May	101	1.00 PM	90
June	108	2.00 PM	105
Jul	101	3.00 PM	120
Aug	93	4.00 PM	135
Sep	85	5.00 PM	150
Oct	77	6.00 PM	165
Nov	69	7.00 PM	180

To calculate the required monthly inclination angle of the heliostat, the ray tracing method is used. If we Let  $\theta$  be the value of sun declination angle with the horizontal, the heliostat stands in 1.5 m above the ground level. When the receiver is the target point, the reflected rays from the heliostat center point must fall in the center of the receiver making an angle equal (A) between the reflected path and the horizontal surface. To find the angle (A), let the distance between the row and tower is (d), and the height of the receiver center point from the heliostat top point is (h), the heliostat length is (L) and the image length is (I) then.

$$A = \tan^{-1} (h / d) \quad (1)$$

and the reflection angle (R) is equal to

$$R = (\theta - A) / 2 \quad (2)$$

Then the complementary for  $\theta$  is

$$\phi = 90 - \theta \quad (3)$$

And for the rays to be reflected to the top of the tower the orientation angle should be

$$O = (\phi - R) \quad (4)$$

And if we let

$$A + O = T \quad (5)$$

The complementary for A and O are



$$\beta = 90 - A \quad (6)$$

$$\sigma = 90 - O \quad (7)$$

The relation to finding the image length is

$$L / \beta = I / \sin T \quad (8)$$

For the hourly tracking the heliostat tilt angle will effect in the width of the image, and for the heliostat side distance (S) from the tower

$$x = \tan^{-1}(h / s) \quad (9)$$

The hourly reflection angle is

$$dR = (180 - \delta - x) / 2 \quad (10)$$

When  $\delta$  is the hour angle

The rotation angle is

$$z = (90 - \delta - dR) \quad (11)$$

Figure-2 shows the orientation angles

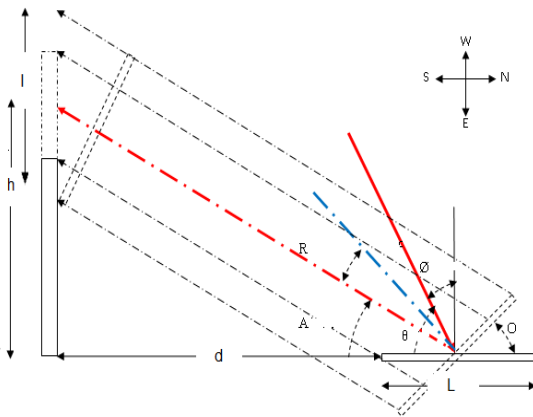


Figure-2. Seasonal orientation angles.

## RESULTS AND DISCUSSION

Referring to the presented dual axis tracking model the heat flux density is found by multiplying the registered value of the irradiance with the formed image area, and the distribution depends on the size and image location and ray formation

The results of the seasonal reflected heliostat image size is shown in Figure-3. It shows that the first row has the lower efficiency and the farthest row is the most efficient in the selected range. Other observation is that for the suggested coordinates the higher efficiency is resulted in the month of July. When the image size is bigger than the real size, that mean spillage loss is happen and the efficiency is less than one. When the image reflection efficiency is equal to unity, that mean the image and real

size are same. For ratio with more than unity the concentration per unit area is increased but the size of the image is less than the real size, that

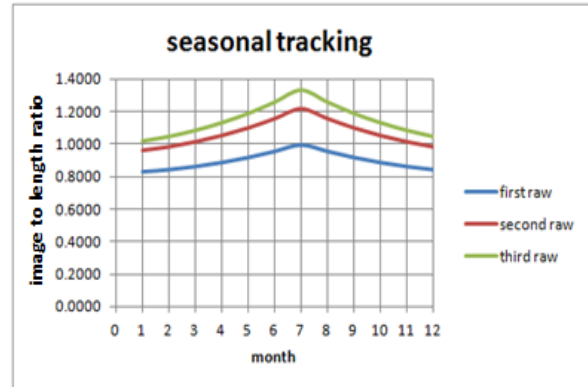


Figure-3. Seasonal tracking efficiency.

Mean the radiation distribution is not perfect for all parts of the receiver, cosine loss is happening and the upper and the lower parts are not received any heat. For the hourly tracking image width formation Figure-4 represents the behaviour of the three heliostat of the first row. It reports that:

At the early hours of the day the heliostat fall in the east side to the tower has the best efficiency than the others. And the ones fall in the middle are the worst efficient. At the end hours of the day the heliostat fall in the west side of the tower has the best efficiency. The same behaviour is observed for the rest of the rows, Figure-5 shows the behaviour of the second row, when Figure-6 shows the third row relation

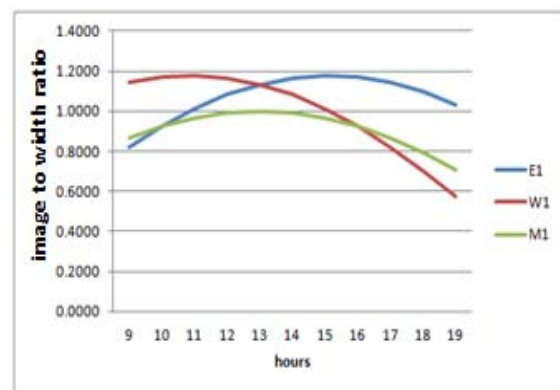


Figure-4. First row hourly tracking image to width ratio.

The total image size can be found by multiplying the hourly tracking formed image length and the seasonal one for each month. Figure-7 shows the total tracking image to heliostat ratio for the first row for the period of twelve months.

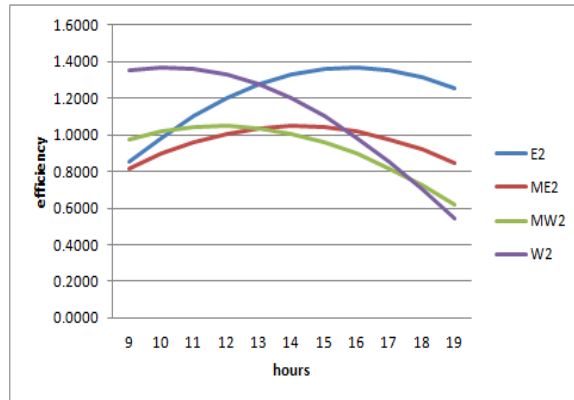


Figure-5. Second row daily tracking efficiency.

To find the field total annual tracking heat flux density a summation of the overall heliostat annual image to heliostat ratio multiplied by the irradiance is required according to the following equation.

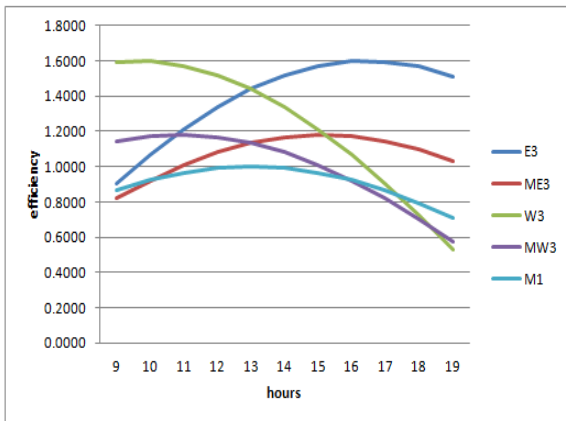


Figure-6. Third row daily tracking efficiency.

$$\eta_{fieldtotal} = \sum_i^3 \eta_{annual} \quad (12)$$

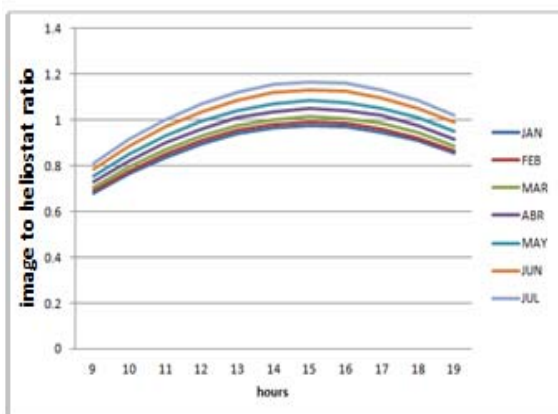


Figure-7. First row annual tracking heat flux density.

## CONCLUSIONS

For the UTP experimental size solar tower suggested space, the heat flux density collected by a dual axis heliostat tracking model is investigated. Simulated results for the field daily and seasonal dual tracking mode efficiency are calculated, experimental validation of the simulated result is expected by the study next step.

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