Optimal Solar Panels' Tilt Angles and Orientations in Kuala Lumpur, Malaysia

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Abstract:

Shading of solar panels drastically reduces the solar collector's efficiency "η" by reducing cell power "P_{MP}", and altering the short circuit-current "I_{SC}", the open-circuit voltage "V_{OC}", and the fill factor "FF". Therefore, the orientation and tilt angle of solar collectors play an important role in minimizing shading and consequently in increasing solar collector's efficiency. A mathematical methodology including Cooper's equation and Visual Basic Application (VBA) programming in Micro soft Excel was utilized to determine optimum tilt angles for solar collectors installed in Kuala Lumpur, Malaysia. The mathematical approach was devised to determine the optimal arrangement in flat fields, field with steps and inclined field. The result indicates that the worst shading effects happens during December and an optimum flat distance between solar collector rows for a flat field is 2.66 m for a 2 meter high collector meanwhile for field with steps and inclined field, the arrangement of solar panel is depended on slope or tilt angle ß which is presented in relevant graphs. The result is useful for the contractors, developers and consulting firms who are running projects in Kuala Lumpur Malaysia.

Keywords: Solar panel, optimizing distance, Optimum tilt angle

Nomenclature

δ= Declination angle
n= Day of the year
φ= Latitude
H= Collector height
ß= Tilt angle
γ= Surface azimuth angle
ßi=Collector tracking axis incident angle
θi=Incident angle for surface with slope
x= distance between collectors
l=length of collectors
y=the height of next row elevates above frontal row
α= Solar altitude angle
ω= Hour angle
θz= Zenith angle
θ= angle of incident
λ= the slope angle of the land surface
R_b =Ratio of beam radiation on collector surface

1. Introduction

The world has realized that sustainable development is the only remedy that can save our planet [1, 2]. Solar energy is one of the cleanest, emission free and sustainable energy which has been introduced as a remedy to combat the millennium environmental crises [3, 4]. Use of renewable energy is not any more a luxurious gesture of developed countries whereby even developing countries are moving forwards to use renewable energy [5]. In this system a solar collector serves to capture the incident solar energy, and to convert it into a more suitable form of energy such as electricity or heat. Solar collectors provide a means by which the converted energy may be transported to the point of usage). There are two types of solar collectors that convert solar rays to electricity and heat namely Photo Voltaic (PV) and solar thermal [6]. Both of these two systems will fail to perform well if they face shading effects [7]. Shading drastically reduces the solar collector's efficiency "η" by reducing cell power "P_{MP}", and altering the short circuit-current "I_{SC}", the open-circuit voltage "V_{OC}", and the fill factor "FF" [8]. The shading on a collector may be cast by its neighbor and/or by a fence, and is dependent on the spacing between collectors, and on collector height, row length, tilt angle and latitude location [9].

However, large scale solar energy systems often employ multiple rows of collectors on a horizontal surface [10]. Usually these rows will be along an east-west axis with the collectors tilted toward the equator [11]. When the rows are relatively far apart there is little shading [12]. Nevertheless, in some applications (e.g. a building roof) the space for installation is limited [12]. Relatively close spacing may be considered as a solution. Moreover, it is important to be able to determine the shadow caused reduction in net radiation flux on the collectors accurately.

This study aims to utilize a mathematical approach to determine the optimal arrangement of the solar panels in flat fields, field with steps and inclined field.

This paper is organized in following sections: Theory and framework, methodology, result and conclusion.

2. Theory and framework

The sun appears to move in a circular orbit around the earth when viewed from a location on the earth [13]. Although this view is physically incorrect, it is convenient and is used for the purposes of terrestrial solar design [13]. The sun is assumed to be located on the celestial (Bird, 1983). This is an imaginary sphere centered at the earth's center and located at a sufficiently large distance from the earth that the locations of the sun. A body moving on sphere has two degrees of freedom in its motion. This study specifies the two degrees of freedom by angles, and two angles are sufficient information to locate the sun on the celestial sphere at any time.

The altitude angle and azimuth angle are two important parameters for solar design projects. The azimuth angle is measured in the horizontal plane between the due-south direction and the projection of the sun-earth line onto the horizontal plane. Azimuth angles have a sign convention, as do other solar angles[14]. The altitude angle depends on three fundamental angles: the solar declination (δ), the latitude (ϕ), and the solar hour angle (ω) [14] (see Fig1).

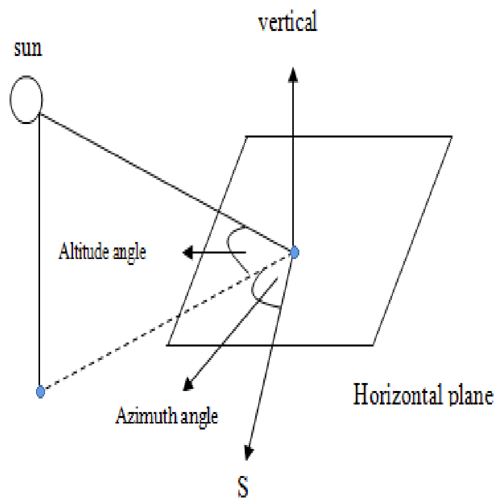

Fig 1: solar altitude angle and solar azimuth angle

The solar declination angle is the same as the latitude at which the sun is directly overhead on a given day. These values of latitude lie between the tropics of Cancer and Capricorn and have a variation of $\pm 23.5^{\circ}$ during a year[15]. Alternatively, the declination can be thought of as the angle between the overhead point for an observer on the equator and the position of the

ISBN: 978-1-61804-122-7

sun at noon on a given day [15]. This is equivalent to the earlier definition. The solar declination angle varies slowly and can be considered constant for a specific day.

The solar azimuth angle measures the relation of the sun facing south, depends on the same three angles as the solar altitude angle [16]. Following equation can be used to calculate the solar azimuth angle:

$$\gamma = \sin^{-1}\left[\frac{\cos\delta * \sin\omega}{\cos\alpha_s}\right] \qquad (1)$$

The azimuth angle is greater than 90° for some hours of the day when the length of day is greater than 12hrs. Therefore the above equation must also be evaluated for the time of year for which a calculation is being made. Near sunrise and sunset on days between March 21 and September 21 the azimuth angle is greater than 90°.

3. Methodology

The study employs a theoretical approach embedding a mathematical methodology including Cooper's equation and Visual Basic Application (VBA) programming in Micro soft Excel. Avoiding shadow is inevitable and shadow's length changes from infinity at sunset and sunrise to the minimum at noon time. Moreover, the length of the shadow is the tallest length at winter for the northern hemisphere. On the flat field, the solar panels are fixed in horizontal level in rows after each other by distance (x). Those panels have a tilt angle of (ß) with and length of (l). Therefore, the ratio of the required distance to obtain the optimum arrangement i.e. arranging the rows in a way that no shadow falls of the first row on the followed row will be calculated by following formula (see Fig 2). $\frac{x}{l} = \frac{\sin ß}{Tan\ \alpha} = + \cos ß$. (2)

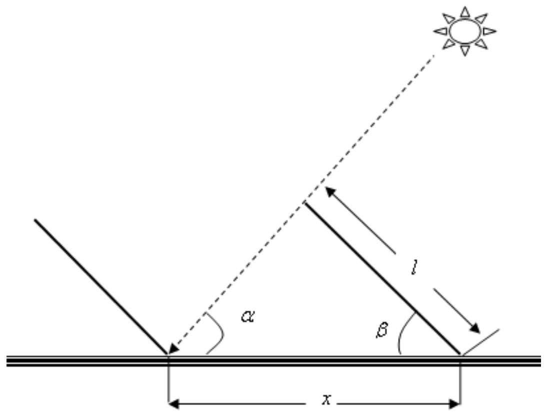

Figure 2: Diagram of flat field

Referring to Duffe and Beckman formula
$\sin\alpha = \cos\varphi \times \cos\delta \times \cos\omega + \sin\varphi \times \sin\delta$
(3)
Also solar altitude angle can be calculated as:

$$\cos\theta_z = \sin(90 - \theta_z) = \sin\alpha \quad (4)$$

The solar latitude for our case study in Kuala Lumpur is $\varphi = 3.1$

In this formula, ω is the hour angle which is chosen at 8:00 am (15 ° per hour time, 3 hour before noon). The hour angle (-60) negative at morning and δ is given as follows. In this formula n is the day of the year.

$$\delta = 23.54 \times \sin(360\frac{284+n}{365}) \qquad (5)$$

For field with steps, the solar panels are arranged in rows after each other where a new row is elevated behind another row by a height as (y) and a distance of (x). For avoiding shading, one can use the following formulas (see Fig 3)

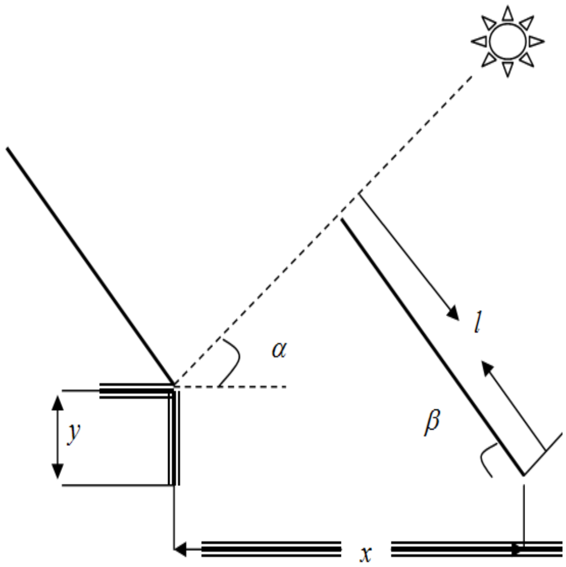

Fig 3 Field with steps

$\frac{y}{l} = \sin\beta + tan\alpha(cos\beta - \frac{x}{l})$ (6)

For inclined filed if there is a slope in the land surface of angle (γ), therefore the slope angle of solar conversion unit would be relative to the level of inclined land (S), where
$\beta = s + \gamma$ (7)
(see Fig 4).
Therefore, the ratio required to obtain the optimum arrangement and to avoid the shadow fall of first surface on the second, (x), to the length of the solar collector (l), is :

$$\frac{x}{l} = \left[\cos(S+\lambda) + \frac{\sin(S+\lambda)}{\tan\alpha}\right] \Big/ \left[1 + \frac{\tan\lambda}{\tan\alpha}\right]$$
(8)

$$cos\theta = sin\gamma sin\varphi cos\beta - sin\gamma cos\varphi sin\beta cos\gamma + cos\delta cos\varphi cos\beta cos\omega + cos\delta sin\varphi sin\beta cos\gamma cos\omega + cos\delta sin\beta sin\gamma sin\omega$$

(9)

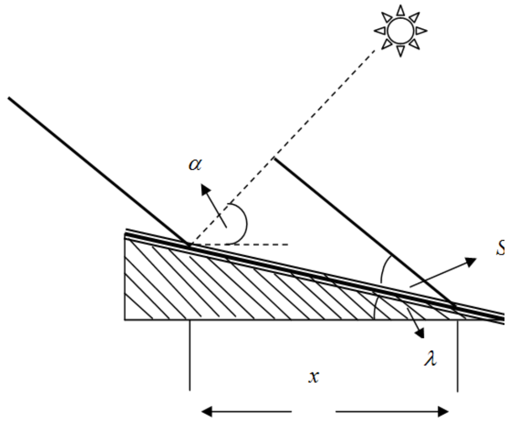

Fig 4 Inclined filed

4. Results and discussions

The following subsections discuss the result of three types of configurations namely: flat field, filed with steps and inclined fields.

4.1. Flat field

This study analyzed the effects of tilted angle to different degrees aiming to get the optimum angle between the angles. For that the declination was figured out at 15th of every months of Kuala Lumpur city (see Fig 5).

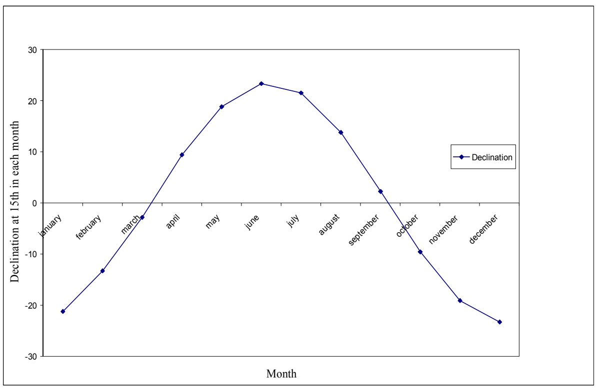

Fig 5: Kuala Lumpur Solar declination

Knowing the solar declination angle assists calculating the zenith angle (θ_z) and the hour angle (see Table I). In this study (8.00 am) hour angle was selected.

Table 1: Summary of data for flat field

Day of month	Declination (δ)	hour angle (ω)	zenith angle (θ_z)	solar altitude (α)
15-Jan	-21.27	-60	63.49	26.51
15-Feb	-13.28	-60	61.71	28.29
15-Mar	-2.82	-60	60.25	29.75
15-Apr	9.415	-60	59.92	30.1
15-May	18.8	-60	60.68	29.31
15-Jun	23.31	-60	61.36	28.64
15-Jul	21.52	-60	61.1	28.93
15-Aug	13.78	-60	60.17	29.83
15-Sep	2.22	-60	59.93	30.06
15-Oct	-9.59	-60	61.08	28.92
15-Nov	-19.15	-60	62.97	27.03
15-Dec	-23.34	-60	64.04	25.95

By knowing these variables and the length of the collectors and the slope angle of the collector; we can obtain the height of the collector and then the distance between the collectors.

The results obtained for the flat field is presented in Fig 6. The biggest distance is needed in December, when the altitude angle is the smallest value. Moreover, at any angle of slope angle the distance increases in this month.

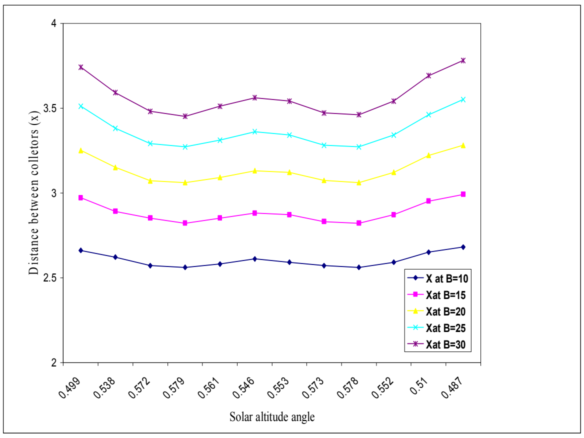

Fig 6 The distance between collectors on flat field area

4.2 Field with steps

Value of the steps that should be elevated frontal row by a height (y), and the distance separating between rows taken from the previous case at the maximum distance ($x = 2.68m$) is presented in Fig 7. The height of (y) changes by alteration of the solar altitude angle during the year. It also depends on the slope angle.

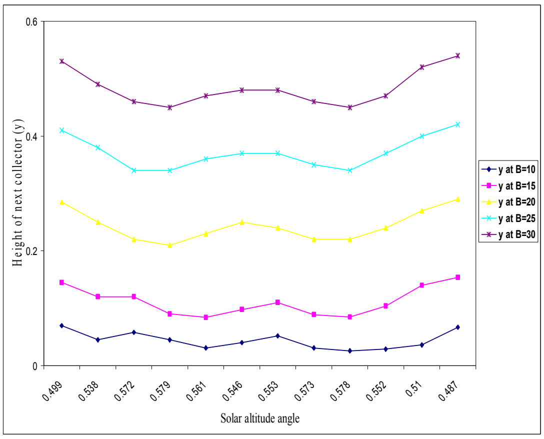

Fig 7: The height of the next row above frontal row by (y)

The results shows that the maximum height of (y) is in December and the minimum is in September. The height of (y) under (10°) slope is very small and by increasing the slope angle the height of (y) increases either.

ISBN: 978-1-61804-122-7

4.3 Inclined field

The third case when the field is inclined by angle (λ), knowing the inclined angle then we can know the slope angle. The ratio required to arrange the rows collectors and avoid the shadow fall of the first surface on the second, (x) to the length of solar collector (l), is the solar altitude angle during the year. Fig 8 shows the ratio between the solar altitude angle and the distance between collectors at 15th each month a year.

Fig 8 The distance between collectors in inclined field

5. Conclusion

The study concludes that the worst shading effects happens during December and an optimum flat distance between solar collector rows for a flat field is 2.66 m for a 2 meter high collector meanwhile for field with steps and inclined field, the arrangement of solar panel is depended on slope or tilt angle ß which is presented in relevant graphs. The suitable angle for Kuala Lumpur location is ($\beta = 10^{\circ}$).

It is also concluded that the tilting angle of a solar collector should be appropriate to receive maximum solar radiation and to avoid shading. Moreover, the spacing between solar rows must be taken in account in large scale solar system.

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