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Design of optimal installation tilt angle and front-to-back spacing for photovoltaic arrays under multiple models

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ABSTRACT

This paper presents the optimal installation dip and front-to-back spacing design model for stationary solar photovoltaic arrays facing the equator, including the solar radiation meteorological model, the Klein model and the Hay model, and then using Matlab software to build the model for simulation and calculate the relevant Solar energy and weather data. By comparing with the solar energy and meteorological data of Zhuhai collected by NASA's surface meteorological and solar energy website, the accuracy of the model was verified. Finally, the optimum installation inclination and spacing between front and rear are designed in Zhuhai City, and the most solar photovoltaic arrays in Zhuhai were obtained. The optimum installation inclination, distance between front and back and the corresponding solar radiation of the solar photovoltaic arrays in Zhuhai City are calculated.

Keywords: Photovoltaic array, Optimum installation inclination, Solar radiation, front-to-back spacing

INTRODUCTION

Solar photovoltaic power generation is based on the photovoltaic effect of semiconductor materials. It mainly converts light energy into electric energy through a series of components. Solar photovoltaic power generation process is simple, no mechanical rotating parts, no fuel consumption, no pollution, no noise, and zero emission. Compared with wind power generation, biomass power generation and nuclear power generation, it is a renewable energy generation technology with the most ideal characteristics of sustainable development.

For photovoltaic power generation system, the installation form and angle of photovoltaic array will affect the amount of solar radiation received by photovoltaic array, and the power generation of photovoltaic array is directly proportional to the amount of solar radiation received by photovoltaic array. Therefore, the installation of photovoltaic arrays and the angle of the system will have a great impact on the generation capacity [8].There are two types of photovoltaic array installation: fixed installation and automatic tracking. Nowadays, Due to the technical and cost constraints of large photovoltaic power plants in China, their photovoltaic arrays are usually fixed and installed. For a fixed photovoltaic array, once installed, the azimuth and inclination will not change. In order to receive more solar radiation, the surface of the array is preferably oriented toward the equator (i.e., azimuth is 0°) according to the law of sun-earth motion, and in the northern hemisphere towards the south and the southern hemisphere towards the north [9].The optimal installation inclination is to make the tilt of the photovoltaic array to receive the largest amount of radiation throughout the year. The optimum installation inclination of photovoltaic arrays is related to the geographic latitude of the installation. Because of the regional difference the installation situation of each region is different. Therefore, it is necessary to design the optimum installation inclination of photovoltaic arrays in different regions.

Under the principle of optimal installation inclination, the spacing determination before and after the array also affects the efficiency of photovoltaic power generation. How to put more photovoltaic panels in a limited space and without affecting the efficiency of photovoltaic panels is also a problem worth studying. Moreover, as with the optimal installation inclination, the determination of the front-to-back spacing of the array is also related to the geographical latitude of the installation, and it is also necessary to design according to different regions.

MODEL INTRODUCTION

2.1 Solar Radiation Meteorological Model

The solar elevation angle h is the angle at which the sun's parallel light intersects the horizontal plane. It is affected by latitude ψ , the solar declination δ at a hour angle ω (i.e., the rotation of the earth per unit of time).The solar elevation angle h expression:

$$\sin h = \sin\psi \cdot \sin\delta + \cos\psi \cdot \cos\delta \cdot \cos\omega \quad (1)$$

the solar declination δ is the angle between the solar incident light and the equator of the earth.The solar latitudes vary from +23.5 °to -23.5°in a year with positive values in the northern hemisphere and negative values in the southern hemisphere. The formula for calculating the solar declination is as follows:

$$\delta = 23.5\sin[360° \times \frac{(284+n)}{365}] \quad (2)$$

The solar elevation angle h and the solar declination δ is as shown in figure 1:

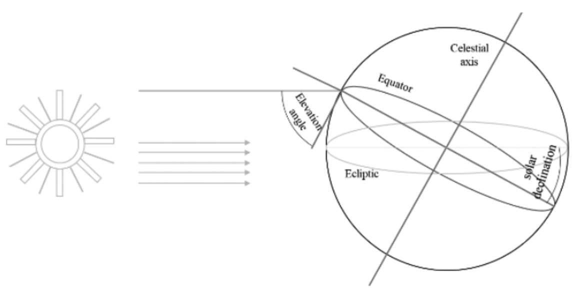

Fig.1 The solar elevation angle and the solar declination diagram

Hour angle ω is to convert time to angle.The local sun is 0°at noon (15°per hour),it will plus in the afternoon and minus in the morning.

$$\omega = 15° \times (\text{Local solar time - } 12) \quad (3)$$

In the formula (3) the local solar time is 24 hours.When it is at noon,the sun's altitude :

$$h = 90° - \psi + \delta \quad (4)$$

The solar elevation angle is 0, that is:

$$\sin 0 = \sin\psi \cdot \sin\delta + \cos\psi \cdot \cos\delta \cdot \cos\omega$$

Solution:

$$\omega = \arccos(-\tan\psi \cdot \tan\delta) \quad (5)$$

$+\omega$ and $-\omega$ are sunset hour angle and sunrise hour angle respectively.

Atmospheric transparent coefficients P is the ratio of the radiance of sunlight through an atmospheric mass to the radiance before passing through. It is a number less than 1,that is:

$$P_m = \frac{S_m}{S_{m-1}} \quad (6)$$

The amount of solar radiation from the upper boundary of the atmosphere passing through m atmospheric masses is:

$$S_m = S_0 \cdot P_m \quad (7)$$

Because solar radiation is weakened through the atmosphere, it also has about 35 percent can reach the surface. The atmospheric transparency coefficient P can be obtained by formula (7).

The total solar radiation on the ground consists of direct solar radiation and sky scattering radiation [14].

The expression of direct solar radiation in a horizontal planeÿ

$$S' = \frac{T}{2\pi} \cdot \gamma \cdot S_0 \cdot \int_{-w_s}^{+w_s} \cdot P_m \cdot \sin h \cdot dw_s \quad (8)$$

The expression of γ :

$$\gamma = 1 + 0.033\cos(\frac{360n}{365}) \quad (9)$$

The expression of sky scattering radiation:

$$D = \frac{T}{2\pi} \cdot \gamma \cdot S_0 \cdot \int_{-w_s}^{+w_s} \cdot P_m \cdot (1 - P_m) \cdot \sin h \cdot dw_s \quad (10)$$

The total solar radiation intensity of the ground:

$$Q = S' + D \quad (11)$$

2.2 Optimal inclination model

To determine the amount of solar radiation on the inclined plane toward the equator, the calculation method proposed by Klein is usually used: the total solar radiation on the inclined plane H_T onsists of direct solar radiatio H_{bt} , sky scattering radiation H_{dt} and ground reflection radiation H_γ [15].The schematic diagram is shown in figure 2:

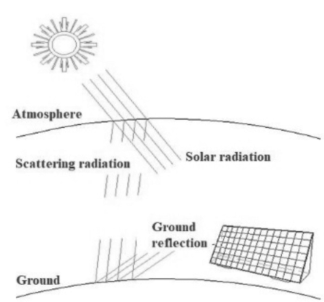

Fig. 2 direct solar radiation, scattering and surface reflection schematic

The formula:

$$H_T = H_{bt} + H_{dt} + H_\gamma \tag{12}$$

The expression of H_{bt} and direct radiation on horizontal plane $H_b (H_b = S')$:

$$H_{bt} = H_b \cdot R_b \tag{13}$$

In determining the slope toward the equator, the expression of R_b :

$$R_b = \frac{\cos(\varphi\text{-}\beta)\ \cos\delta\ \sin\tau_s' + \frac{\pi}{180}\tau_s'\ \sin(\varphi\text{-}\beta)\ \sin\delta}{\cos\varphi\ \cos\delta\ \sin\tau_s + \frac{\pi}{180}\tau_s\ \sin\varphi\ \sin\delta} \tag{14}$$

The ω_s' expression of the hour angle at sunset on the inclined plane such as formula (15):

$$\omega_s' = \min\{\omega_s \cdot \cos^{-1}[-\tan(\psi\text{-}\beta)\tan\delta]\tag{15}$$

The Hay heterogeneity distribution model considers that the amount of sky scattering radiation on the inclined plane towards the equator is composed of two parts: the amount of radiation from the solar disc and the scattered radiation from the other sky dome [16].Its expression is as shown in expression (16)

$$H_{dt} = H_d[\frac{H\text{ - }H_d}{H_0}R_b + \frac{1}{2}(1\text{ - }\frac{H\text{ - }H_d}{H_0})(1+\cos\beta)] \tag{16}$$

The expression H_0 of horizontal radiation out of the atmosphere is:

$$H_0 = \frac{24\times3600}{\pi}S_0(1+0.033\cos(\frac{360°n}{365}) (\frac{\pi\omega_s}{180°}\sin\phi\ \sin\delta+\cos\phi\ \cos\delta\sin\omega_s) \tag{17}$$

Surface reflection radiation constant H_γ formula:

$$H_\gamma = \frac{1}{2}\rho H\,(1\text{-}\cos\beta) \tag{18}$$

As a result, the formula for the total amount of solar radiation on the inclined plane could read as follows:

$$H_T = H_bR_b + H_d[\frac{H\text{ - }H_d}{H_0}R_b + \frac{1}{2}(1\text{ - }\frac{H\text{ - }H_d}{H_0}) (1+\cos\beta)]+\frac{1}{2}\rho H\,(1\text{-}\cos\beta)] \tag{19}$$

For a given location, H_T to β is deribed and make $\frac{dH_T}{d\beta} = 0$ .Figure out the formula (20):

$$\beta_{opt} = \text{arc}\tan[\frac{2\frac{H_b}{H}+2\frac{H_b}{H_0}\left(1\text{-}\frac{H_b}{H}\right)}{\frac{H_b}{H}+\frac{H_b}{H_0}\left(1\text{-}\frac{H_b}{H}\right)+(1\text{-}\rho)} \times \frac{\tan^2\psi\tan\omega_s+\frac{\pi}{180}\omega_s}{\tan\psi(\tan\omega_s\text{-}\frac{\pi}{180}\omega_s)}] \tag{20}$$

When the direct radiation is zero, the optimum inclination is not equal to zero, which is the result of the anisotropic model of sky scattering radiation. For the second half of the year, the optimum inclination is usually close to zero or even negative. It is also of practical value to calculate the optimum inclination directly from formula (20) [18].

In the above model, formula (2) can be used to calculate the red latitude, the angle of sunset time of horizontal plane can be obtained by taking the data of the latitude and the red latitude into the formula (5), and the sum of (8) and (10) can be obtained by means of the obtained data. The direct radiation of horizontal plane and the amount of scattering radiation in horizontal plane are calculated respectively. Formula (15) is used to calculate the angle of inclined plane at sunset. Thus, the data can be brought into the formula (20) to calculate the optimum installation inclination angle, and then according to the obtained optimum installation inclination angle, Formula (8), formula (13) and formula (14) are used to calculate the amount of direct solar radiation on the inclined plane, and formula (16) and formula (17) are used to calculate the amount of scattering radiation on the inclined plane, The formula (18) is used to calculate the amount of reflected radiation on the slope surface, and the total amount of solar radiation on the inclined plane is calculated by formula (19).

ESTABLISHMENT OF MODEL AND ACCURACY OF CALIBRATION MODEL

Through matlab programming, the proposed model is established into a corresponding formula model, and the calculated data are compared with the actual data, so as to determine the accuracy of the established model and further determine the accuracy of the calculation of the best inclination angle.

3.1 Acquisition of Meteorological Data

In order to verify the accuracy of the model, it is crucial to obtain accurate and detailed meteorological data such as sunset time angle, horizontal scattering, horizontal direct radiation, etc. However, solar radiation observatories are less distributed in China. With the continuous expansion of the construction area of photovoltaic power plants, the radiation data obtained by local meteorological departments can not meet the needs of the calculation of radiation in photovoltaic system design. Therefore, it is necessary to obtain the horizontal irradiation data through other ways to calculate the irradiation on the inclined plane in order to determine the inclination of the photovoltaic system. At present, in the design of photovoltaic systems, NASA meteorological websites and RETScreen meteorological websites are generally used to obtain horizontal meteorological data. In this paper, the data of Zhuhai City (latitude 22.27, longitude 113.53) will be queried on NASA Surface Meteorology and Solar Energy to verify the model.

3.2Comparison of Solar Declination

The solar declination has nothing to do with the location, but only the number of days in the year (N), and the same solar declination anywhere on the planet. Through the calculation of the model, it is found that every month in Zhuhai City, the solar declination is as shown in Table 1:

TABLE 1

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Declination	-20.89	-13.35	-2.39	9.51	18.85	23.13	21.15	13.32	2	-9.87	-19.09	-23.14

By using the plot command in matlab, the query data and the monthly data calculated by the model are compared through the graph. The results are shown in fig.3:

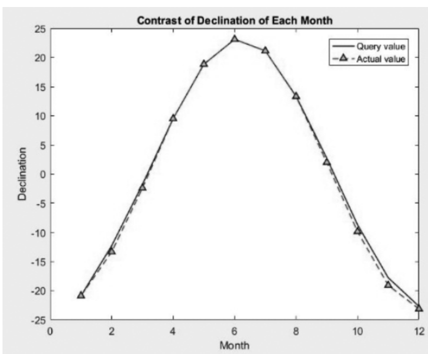

Fig. 3 Comparison of query values and model calculation values for each month of each month

From Fig. 3, it can be seen that the data calculated from the model are basically consistent with the measured data, which shows that the model can reflect the true variation of the solar declination.

3.3 Comparison of Angles at Sunset in Horizontal Plane

By querying the relevant data of Zhuhai City (latitude 22.27, longitude 113.53) on NASA's terrestrial meteorology and solar energy website. We have obtained the relative data of angle and scattering radiation of horizontal plane at sunset in Zhuhai City. The daily mean of the angle at sunset for each month is shown in Table 2:

Table 2 NASA data of monthly horizontal sunset angle

Monthly Averaged Sunset Hour Angle (degrees)												
Lat 22.27	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lon 113.53												
Average	81	84.8	89.2	94	98	100	99.1	95.7	91.2	86.5	82.2	80

Based on the data of Zhuhai City, the daily average value of the angle at sunset of every month in Zhuhai City is calculated, as shown in Table 3:

Table 3 calculation data of monthly horizontal sunset angle model

Monthly mean level sunset angle(°)												
Lat 22.27	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lon 113.53												
Average	80.97	84.58	89.01	93.9	98.03	100.08	99.15	95.64	90.91	86.02	81.92	79.94

By using the plot command in matlab, the NASA query data are compared with the monthly daily mean values of the monthly horizontal sunset angle calculated by the model. The results are shown in figure 4:

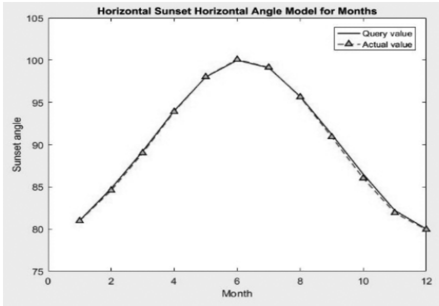

Fig. 4 Comparison of NASA query value and model calculation value of horizontal sunset angle in each month

The comparison of Fig. 4 shows that the value obtained by the model for the angle of horizontal sunset is basically consistent with the data queried by NASA, which shows that the accuracy of the model for calculating the angle of horizontal plane at sunset is very high.

3.4 Comparison of Horizontal Scattering Radiation

The daily average value of monthly horizontal scattering radiation in Zhuhai City is found in Table 4 by NASA.

Table 4 NASA data of monthly horizontal scattering radiation

Monthly Averaged Diffuse Radiation Incident On A Horizontal Surface (kWh/m2/day)

Lat 22.27 Lon 113.53	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	1.44	1.64	1.91	2.21	2.43	2.49	2.47	2.34	2.1	1.75	1.42	1.32	1.96

The daily mean value of monthly horizontal scattering radiation in Zhuhai is obtained by the model calculation, which is shown in Table 5.

Table 5 calculation data of monthly horizontal scattering radiation model

Monthly horizontal scattering radiation (kWh/m2/day)

Lat 22.27 Lon 113.53	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AnnualAverage
Average	1.52	1.76	2.02	2.23	2.34	2.36	2.34	2.26	2.09	1.83	1.57	1.45	1.98

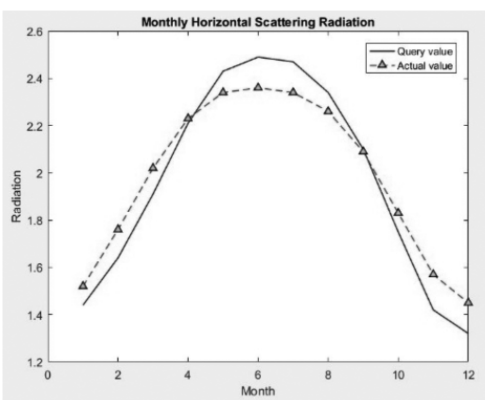

Fig. 5 Comparison of NASA query value and model calculation value of horizontal scattering radiation in each month

Through the plot command in matlab, the daily data of the NASA query and the monthly horizontal scattering radiation calculated by the model are compared by the graph. The results are shown in figure 5:

According to the two curves in Fig. 5, it can be seen that the variation trend of the two curves is basically the same, and the data of each month are similar, which shows that the model can accurately represent the level of scattering radiation in the horizontal plane.

3.5 Comparison of Direct Radiation in a Horizontal Plane

The daily average of monthly direct radiation in Zhuhai is as shown in Table 6 through NASA:

Table 6 NASA data of direct horizontal radiation for each month

Monthly Averaged Direct Normal Radiation (kWh/m2/day)

Lat 22.27 Lon 113.53	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	2.23	2.64	3.01	3.33	3.49	3.6	3.57	3.44	3.25	2.9	2.56	2.3	3.03

The daily mean value of monthly horizontal scattering radiation in Zhuhai is obtained by the model calculation, which is shown in Table 7.

Table 7 calculation data of horizontal direct radiation model for each month

Monthly horizontal direct radiation (kWh/m2/day)

Lat 22.27 Lon 113.53	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Average	2.33	2.7	3.1	3.44	3.6	3.64	3.61	3.48	3.21	2.81	2.42	2.22	2.33

By using the plot command in matlab, the NASA query data and the monthly direct radiative average data calculated by the model are compared through the graph. The results are shown in figure 6:

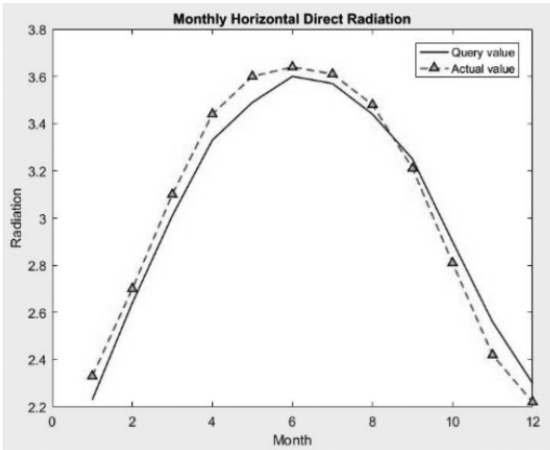

Fig. 6 Comparison of NASA query value and model calculation value of horizontal direct radiation in each month

The variation trend and data of the two curves in Fig. 6 are similar, which shows that the calculation of the direct radiation in the horizontal plane in the model is more accurate.

By using matlab program, combined with the meteorological model of solar radiation quantity and the model of optimum inclination angle, the calculated data of the models such as the declination, the angle at sunset in the horizontal plane, the amount of scattering radiation in the horizontal plane and the direct radiation in the horizontal plane are obtained.By comparing with the query data, we can see that the model can accurately reflect the actual situation.

OPTIMUM INSTALLATION INCLINATION AND SOLAR RADIATION IN ZHUHAI AREA

4.1 Best Installation Inclination in Zhuhai Area

In this paper, matlab programming software is used to design the optimum installation inclination and calculate the solar radiation in Zhuhai. The programming flow is shown in figure 7.

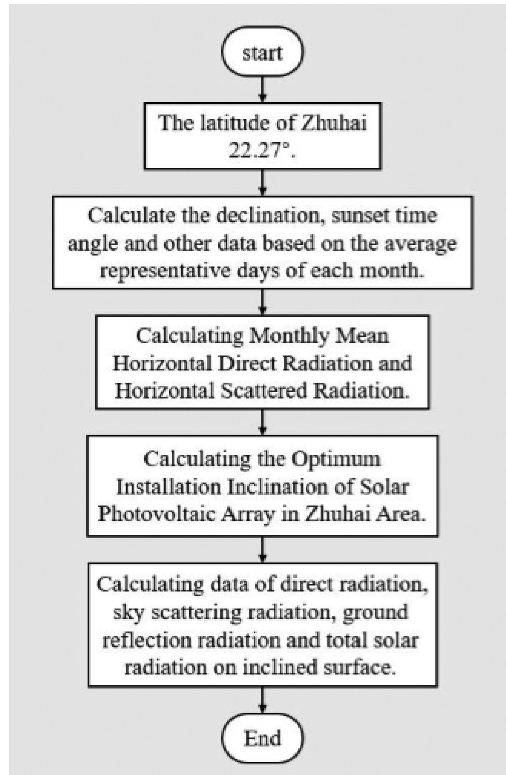

Fig. 7 Program flow chart of optimum installation inclination design and solar radiation calculation in Zhuhai

According to the meteorological model of solar radiation quantity and the calculation model of optimum inclination, the optimum dipping angle and total solar radiation of Zhuhai city are analyzed and calculated. From formula 20, the optimum installation dip angle of Zhuhai is obtained. Table 8 lists the best installation inclination angle for each month and year in Zhuhai City.

Table 8 optimal installation inclination of solar photovoltaic arrays in Zhuhai area

Optimum installation inclination of Solar photovoltaic Array in Zhuhai City (°)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Average	49.78	39.92	25.07	6.71	-7.9	-14.2	-11.49	0.35	18.01	35.4	47.41	52.22	20.1

The photovoltaic system design assistant software PVsyst is used to guide the photovoltaic system design.Input the latitude and longitude of Zhuhai City and altitude (45m), and get the best installation inclination angle of Zhuhai city as figure 8.

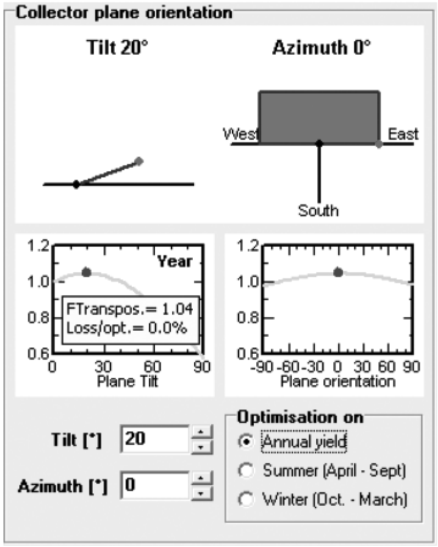

Fig. 8 the best annual installation inclination of Zhuhai obtained by PVsyst

By comparing table 5 with figure 8, it can be seen that the calculation results of the optimum installation inclination angle in Zhuhai are basically consistent, and the accuracy of the calculated results based on the model is proved. Therefore, the optimal annual installation inclination of distributed photovoltaic arrays in Zhuhai is 20.1 °.

4.2 Solar Radiation at Optimum Installation Inclination

4.2.1 Direct Solar Radiation

According to the calculated optimum installation inclination of Zhuhai City, the direct solar radiation H_{bt} on the inclined plane of each month and year under the optimum inclination angle can be calculated by formula 13 as shown in Table 9.

Table 9 Direct solar radiation on inclined plane with optimum installation inclination

Direct solar radiation on inclined plane (kWh/m2/day)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
3.71	3.58	3.45	3.46	3.64	3.76	3.69	3.48	3.39	3.5	3.65	3.73	3.59

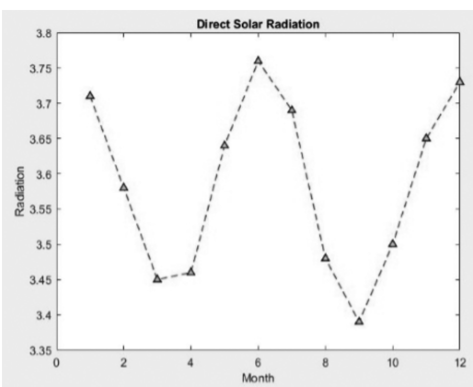

Fig. 9 broken line diagram of direct solar radiation

Fig. 9 shows the variation of direct solar radiation H_{bt} at optimum installation inclination. It can be seen from the figure that the direct solar radiationis higher in summer and winter and lower in spring and autumn under the optimum installation inclination angle, and the highest in June and the lowest in September.

4.2.2 Sky Scattering Radiation

By formula 17, the amount of sky scattering radiationon the slope surface at the optimum installation angle can be calculated as shown in Table 10.

Table 10 optimal installation of sky scattering radiation on inclined plane

The amount of Sky scattering radiation (kWh/m2/day) on the Slope plane												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
1.81	1.93	2.08	2.24	2.34	2.39	2.36	2.26	2.12	1.95	1.83	1.77	2.09

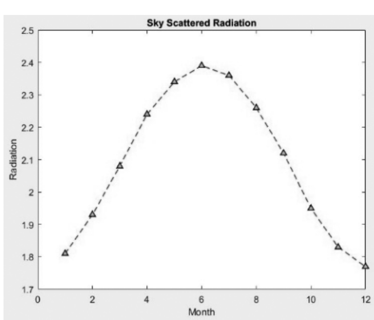

Fig. 10 broken line diagram of sky scattering radiation

Fig. 10 shows the variation curve of sky scattering radiation H_{dt} at optimum installation inclination.It can be seen from figure 10 that the amount of sky scattering radiation H_{dt} at the optimum installation angle is larger in summer, reaches its maximum in June, then decreases, and decreases in winter, and then rises after reaching its lowest value in December.

4.2.3 Ground Reflection Radiation

From formula 19, the amount of radiation H_{γ} reflected from the ground on the slope surface for each month and year under the optimum installation inclination can be calculated as Table 11.

Table 11 ground reflection radiation on the slope surface with optimal installation inclination

Surface reflection radiation on inclined plane (kWh/m2/day)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AnnualAverage
0.49	0.37	0.17	0.01	0.02	0.07	0.04	0	0.09	0.31	0.46	0.51	0.21

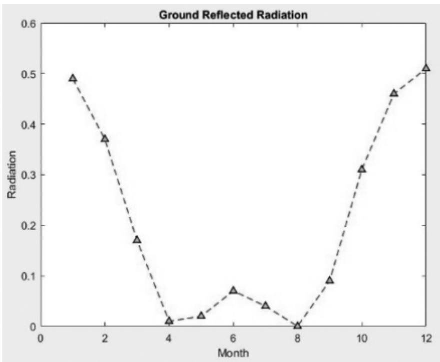

Fig. 11 broken line diagram of reflected radiation on the ground

It can be seen from figure 11 that the amount of radiation H_{γ} reflected on the ground at the optimum installation inclination is small. However, different from the amount of sky scattering radiation H_{dt}, its numerical value is smaller in summer and larger in winter.

4.2.4 Total Solar Radiation on the Slope

The total solar radiation H_T from formula 12 can be calculated for each month and year at the optimum installation inclination, as shown in Table 12.

Table 12 Total solar radiation on the slope of the optimum installation inclination

Total solar radiation (kWh/m2/day) on inclined plane												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
6.01	5.88	5.71	5.71	6	6.22	6.09	5.75	5.6	5.76	5.94	6.01	5.89

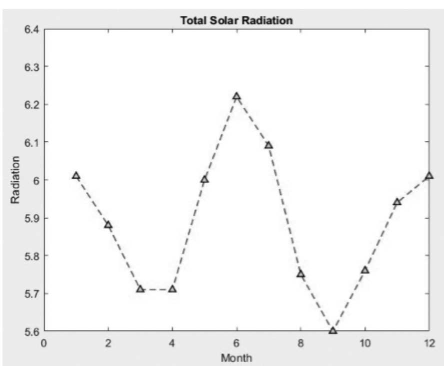

Fig. 12 broken line diagram of total solar radiation

Figure 12 shows the total solar radiation at the optimum installation inclination H_T.Combined with figures 9 to 12, it can be seen that the total solar radiation H_T at the optimum installation inclination angle is similar to the curve of direct solar radiation H_{bt}.The direct solar radiation H_{bt} and sky scattering radiation H_{dt} have a greater impact, but less by the surface reflection radiation H_{γ}.

DETERMINE THE ANTERIOR AND POSTERIOR SPACING OF THE ARRAY

5.1 The Principle of Determining Spacing

In the northern hemisphere, the plane corresponding to the maximum sunshine radiation acceptance is oriented to the south. When the inclination of the array is determined, it should be noted that a reasonable distance between the north and South arrays should be set aside so as to avoid shadow occlusion. The best distance D is defined as the winter solstice day (the longest shadow length of the object in the sun each year) 9:00-15:00, and there is no north-south direction between the components. Shadow shading, photovoltaic array spacing should not be less than D, as shown in the figure. In Figure 13, H is the height of the array, Z is the installation inclination, A is the solar height, L is the projection length, and beta is the angle between the projection and the forward-south direction.

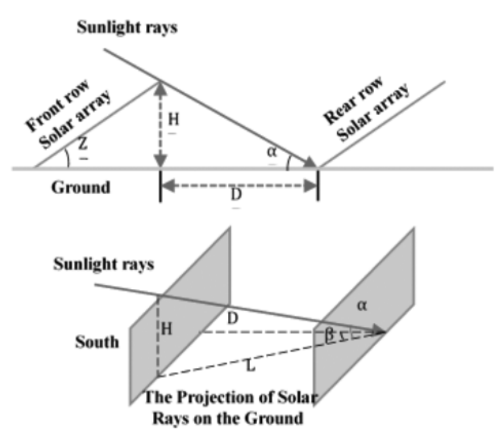

Fig. 13 Calculations of Spacing D

5.2 Determination of Declination Angle

The declination angle is a phenomenon caused by the earth's movement around the sun. It varies with time. Because the direction of the earth's axis remains unchanged, the declination angle has different values with the different points of the earth's orbit. The declination angle moves in the range of $+23.5^{\circ}$ and -23.5° and becomes the symbol of the season. The Sun in the Northern Hemisphere Winter Solstice is on the Tropic of Cancer with a declination angle of.

5.3 Determination of Solar Altitude Angle

The solar altitude angle is the angle alpha between the solar rays and the horizontal surface of the earth's surface. According to the formula:

$$\sin\alpha = \sin y \cdot \sin\delta + \cos y \cdot \cos\delta \cdot \cos b \quad (21)$$

Solar altitude angle can be calculated at every moment. In the formula, y is the local latitude, Zhuhai's latitude is 22.27 degrees; δ is the declination angle, the northern hemisphere winter solstice solar declination angle is - 23.5 degrees; b is the time angle, every 15 degrees is 1 h, 9:00 a.m. is - 45 degrees. Bring relevant data into formula (21):

$$\text{Sin}\alpha = \sin 22.27^{\circ} \sin(-23.5^{\circ}) + \cos 22.27^{\circ} \cos(-23.5^{\circ}) \cos(-45^{\circ}) = 0.4490 \quad (22)$$

It is found that $\alpha = 26.68^{\circ}$. The results show that the solar altitude angle of Zhuhai on the winter solstice is 26.28 degrees at 9:00 a.m.

5.4 Determination of Space

The expression of projection length L:

$$L = H / \tan\alpha \quad (23)$$

The expression of spacing D:

$$D = L\cos b \quad (24)$$

In formula, b is the time angle.

After calculating the local solar altitude angle from Formula 21, the projection length is obtained from Substitution Formula 22, and then the projection length is brought into Formula 23 to obtain the distance D.

Bring in relevant data to get:

$$D = \frac{0.707H}{\tan 26.68^{\circ}} = 1.407H \quad (25)$$

Assuming that the height of solar photovoltaic panels is 1600 mm and arranged in two groups of vertical side-by-side, the design considers the distance of 50 mm. The total height is $2*1600+50=3250mm$ in Zhuhai, and the optimum inclination angle is 20.1 degrees.

$$H = 3250 \times \sin 20.1^{\circ} = 1116.89 \text{ mm} \quad (26)$$

Spacing D is:

$$D = 1.407H = 1571.47\text{mm} \quad (27)$$

According to the above discussion, the distance between the front and back solar photovoltaic panels should be greater than 1571.47 mm when the photovoltaic arrays with a height of 1600 mm and two groups of vertical side-by-side arrangement are adopted. When the light intensity is high, there will be no shadow occlusion. To maximize the efficiency of photovoltaic power generation.

SUMMARY

Using PVsyst, we can get the total solar radiation of Zhuhai horizontal plane, as shown in Table 13.

Table 13 Total solar radiation from horizontal plane in Zhuhai City

Total solar radiation of horizontal plane in Zhuhai City (kWh/m2/day)												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
3.23	2.17	2.27	2.93	4.19	5.02	5.66	5.08	4.77	4.16	3.71	3.3	3.88

The total solar radiation in the horizontal plane is compared with the total solar radiation on the inclined surface at the optimum installation angle by means of a broken line diagram, as shown in figure 13 :

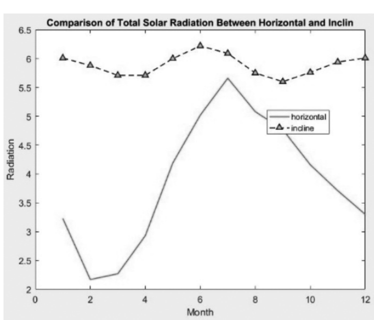

Fig. 14 comparison of total solar radiation between horizontal plane and inclined plane

It can be seen from figure 13 that the total amount of solar radiation on the inclined surface at the optimum installation angle is significantly higher than the total solar radiation on the horizontal plane. The total solar radiation received on the slope plane is 51.8 more than that on the horizontal plane, as calculated by the annual average daily solar radiation of 5.89 on the inclined plane and 3.88 on the horizontal plane. It is shown that the selected dip angle can make the photovoltaic array receive more solar radiation and thus increase the power generation of the photovoltaic system.

In this paper, a meteorological model of solar radiation is used to calculate the sum of direct radiation and scattering radiation in the horizontal plane. The formula of the amount of sky scattering radiation in the Hay model is selected, and the formula of the total amount of solar radiation on the inclined plane is obtained by combining the two formulas with the Klein model, and the optimum installation dip angle is obtained by using the method of derivation. And through reasonable formula calculation, the distance between front and rear installation in Zhuhai area is obtained, which is verified by practical experiments.

The calculation and analysis of the proposed model are realized by using Matlab programming, and the calculated data are compared with the actual data collected. It is proved that the selected model has a high accuracy. On the basis of this, the design of the optimum installation inclination of Zhuhai City is completed, and the optimum installation angle of the fixed photovoltaic array in Zhuhai is 20.1 °per year. According to the optimum installation angle, the monthly and annual mean solar radiation data of the inclined plane are calculated.

In this paper, the accuracy of the proposed model is tested, the reliability of the model is proved, and the optimum installation inclination and front-to-back spacing design of photovoltaic array in Zhuhai is completed. which can be used in practical engineering.

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