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Clear Sky Global Solar Irradiance on Tilt Angles of Photovoltaic Module in Perlis, Northern Malaysia

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Abstract—**The performance of a photovoltaic (PV) is highly influenced by its orientation and its tilt angle with the horizontal, due to the fact that both the orientation and tilt angle change the amount of solar radiation reaching the surface of the PV module. This paper presents a calculation of tilt angle and global solar irradiance on PV module in Perlis, Northern Malaysia. A mathematic method is used to calculate tilt angles and clear sky global solar irradiance, which depend on latitude and day number. The clear sky global solar irradiance consists of beam, diffuse and reflected solar irradiance. The tilt angles and clear sky global solar irradiance change every day in a year and analyzed. The monthly average beam, diffuse, reflected and clear sky global solar irradiance are shown and analyzed in this paper. The tilt angles of PV module in Perlis, Northern Malaysia are -17.16^0 to 29.74^0. The positive, zero and negative tilt angles indicate that the PV module is facing south, on horizontal surface and north, respectively. The monthly average beam solar irradiance give a highest value compared with the diffuse and reflected solar irradiance. The average monthly beam solar irradiance of a year is , 968.36 W/m^2 , diffuse and reflected solar irradiance are 88.22 W/m^2 , and 4.70 W/m^2 , respectively. Based on global solar irradiance of a year, Perlis has a big global solar irradiance potential, its average is 1019 W/m^2. These data show that the clear sky global solar irradiance can be used for certain application, especially in PV power generation.**

Keywords : **solar irradiance, tilt angles, photovoltaic module**

I. INTRODUCTION

The performance of a photovoltaic (PV) is highly influenced by its orientation and its tilt angle with the horizontal, due to the fact that both the orientation and tilt angle change the amount of solar radiation reaching the surface of the PV module, presented by [1]. The tilt angle of the fixed-structure PV module should be carefully evaluated for different places and periods of time to obtain the maximum overall output electrical energy. A mathematical model was used by [2] to estimate the global solar irradiance on the tilt PV surface, and to determine optimum tilt angles for PV module, the optimum tilt angle were determine by searching for the value of angle for which the global irradiance on the PV module surface was maximum. Empirical correlation for estimating the diffuse solar irradiance incident on horizontal surface have been proposed by [3], the result shown that in Jeddah (Saudi Arabia), the solar irradiance have to be tilted to face south with a tilt angle equals the latitude of the place in order to achieve the best performance all year round. The optimal PV tilt angle and orientation depend on the local climate, the load consumption temporal profile and latitude. Research result of [4] shown that using PV mounting structure of adjustable tilt angle can be obtained PV performance improvement of 5.6%.

This paper presents a calculation of tilt angle and global solar irradiance on PV module in Perlis, Northern Malaysia. Method of [5] is used to calculate tilt angle and global solar irradiance, which depend on latitude and day number. The global solar irradiance consists of beam, diffuse and reflected solar irradiance. The tilt angle and global solar irradiance change every day in a year and analyzed. The monthly average beam, diffuse, reflected and global solar irradiance are shown and analyzed in this paper.

II. METHODOLOGY

A. Latitude and climate of Perlis, Northern Malaysia

Based on Malaysia Meteorological Department [6], Malaysia naturally has abundant sunshine and thus solar radiation. However, it is extremely rare to have a full day with completely clear sky even in periods of severe drought. The cloud cover cuts off a substantial amount of sunshine and thus solar radiation. On the average, Malaysia receives about 6 hours of sunshine per day.

Based on Meteorological Station in Chuping Perlis, Perlis (6^0 29' N , 100^0 16' E) as shown in Fig.1 has about 795 square kilometers land area, 0.24% of the total land area of Malaysia, with a population about 204450 people [6]. Perlis's climate is tropical monsoon. Its temperature is relatively uniform within the range of 21°C to 32°C throughout the year. During the months of January to April, the weather is generally dry and warm. Humidity is consistently high on the lowlands ranging 82% to 86% per annum. The average rainfall per year is 2,032 mm to 2,540 mm and the wettest months are from May to December.

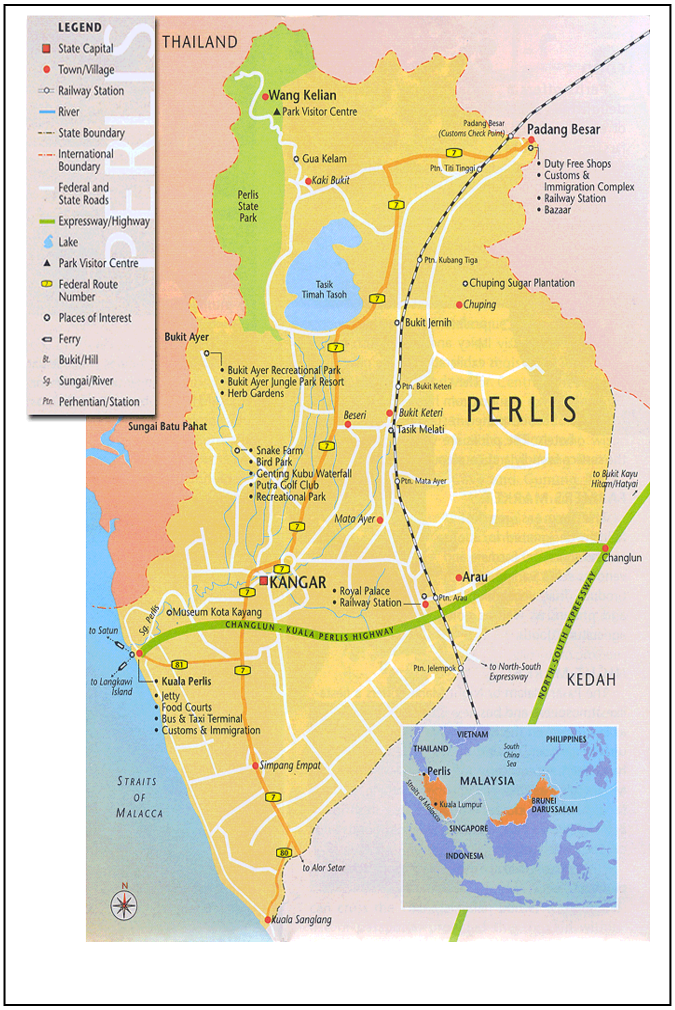

Figure 1. Map of Perlis has latitude $6^0\ 29^{'}$ N

B. Solar Irradiance

The electricity power generated by PV systems is directly related to the solar energy received by the PV module, while the PV module can be placed at any orientations and any tilt angles, but most local observatories only provide solar irradiance data on a horizontal surface. Thus, an estimation of the solar irradiance on a tilt surfaces is calculated by adding the beam, diffuse, and reflected solar irradiance components on the tilt surface together by [5], as in Fig. 2. The total solar irradiance on tilt surface is given by :

$$I_{tt} = I_{bt} + I_{dt} + I_{rt} \qquad (1)$$

where I_{tt} is the total solar irradiance on the tilt surface, W/m^2; I_{bt} is the total beam solar irradiance absorbed by the tilt surface, W/m^2; I_{dt} is the total diffuse solar irradiance absorbed by the tilt surface, W/m^2; and I_{rt} is the total reflected solar irradiance absorbed by the tilt surface, W/m^2.

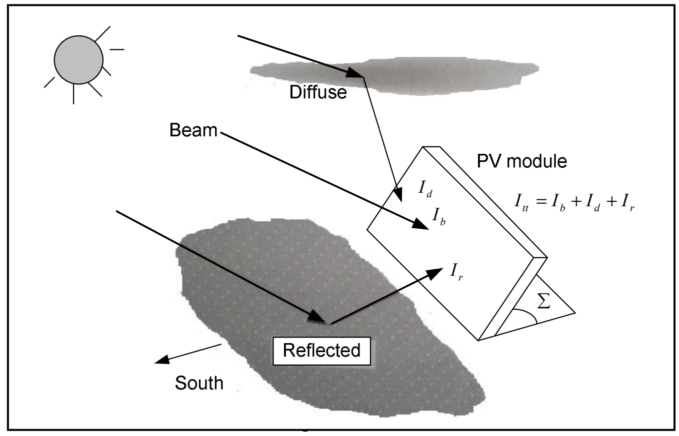

Figure 2. Total solar irradiance on tilt surface of PV module

C. Tilt Angle of a PV Module

An altitude angle or solar angle β_N is an angle between the sun and the local horizontal directly beneath the sun. The altitude angle of the sun at solar noon is shown in Fig. 3.

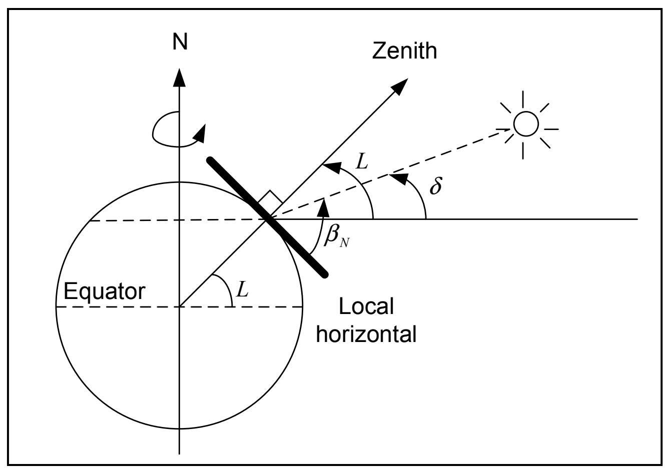

Figure 3. The altitude angle of the sun at solar noon

From Fig. 3 can be written down the following relationship by inspection:

$$\beta_N = 90^0 - L + \delta \qquad (2)$$

$$\Sigma = 90^0 - \beta_N \qquad (3)$$

where L is the latitude of the site, δ is solar declination (the angle formed between the plane of the equator and a line drawn from the centre of the sun to the centre of the earth) and Σ is tilt angle of PV module. According to [5], the solar declination δ is given by:

$$\delta = 23.45 \sin\left[\frac{360}{365}(n-81)\right] \quad (4)$$

where n is day number, with January 1 as day 1 and December 31 being day number 365.

D. Beam Solar Irradiance

The translation of direct-beam irradiance I_b (normal to the rays) into beam into beam irradiance striking a PV module face I_{bt} is a simple function of the angle of incidence θ between a line drawn normal to the PV module face and the incoming beam irradiance (Fig. 4). It is given by

$$I_{bt} = I_b \cos\theta \quad (5)$$

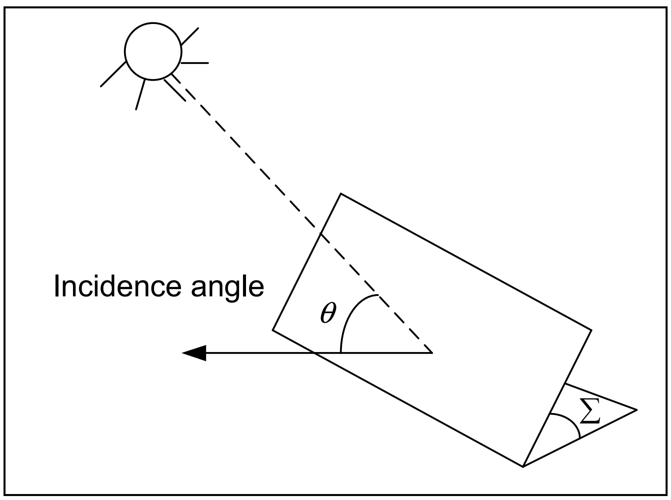

Figure 4 The incidence angle θ between a normal to the PV module face and the incoming solar beam irradiance

where I_b is the beam portion of the radiation reaching the earth's surface (normal to the rays), is given by

$$I_b = Ae^{-km} \quad (6)$$

where A is an "apparent" extraterrestrial flux, and k is a dimensionless factor called the optical depth, given by

$$A = 1160 + 75\sin\left[\frac{360}{365}(n-275)\right] \quad (7)$$

$$k = 0.174 + 0.035\sin\left[\frac{360}{365}(n-100)\right] \quad (8)$$

The air mass ratio m is given by

$$m = \frac{1}{\sin\beta} \quad (9)$$

The angle of incidence θ will be a function of the photovoltaic orientation and the altitude and azimuth angles of the sun at any particular time. Fig. 5 introduces these importance angles. The photovoltaic is tipped up at angle Σ and faces in a direction described by its azimuth angle ϕ_P (measured relative to due south, with positive value in the southeast and negative value in the southwest). The incidence angle is given by

$$\cos\theta = \cos\beta\cos(\phi_S - \phi_P)\sin\Sigma + \sin\beta\cos\Sigma \quad (10)$$

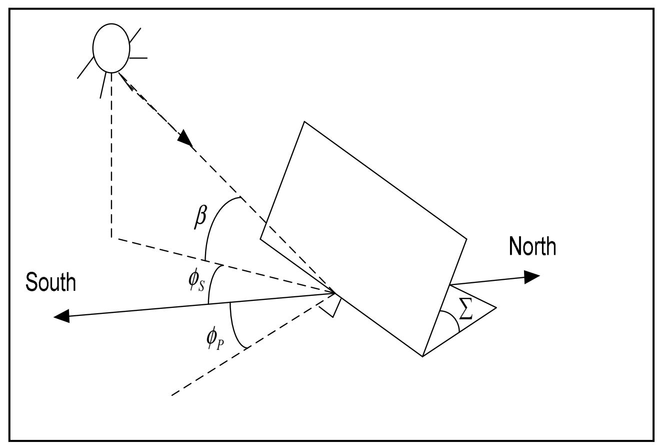

Figure 5. Illustrating the PV azimuth angle ϕ_P and tilt angle Σ along with the solar azimuth angle ϕ_S and altitude angle β. Azimuth angles are positive in the southeast direction and are negative in the southwest

The solar azimuth angle ϕ_S is given by [7]

$$\sin\phi_S = \frac{\cos\delta\sin H}{\cos\beta} \quad (11)$$

where H is hour angle (the number of degrees that the earth must rotate before the sun will be directly over local meridian or line of longitude), is given by [8]

$$H = \cos^{-1}(-\tan L\tan\delta) \quad (12)$$

E. Diffuse Solar Irradiance

The simplest models of diffuse irradiation assume it arrives at a site with equal intensity from all direction; that is, the sky is considered to be isotropic. Obviously, on hazy or overcast days the sky is considerably brighter in the vicinity of the sun, and measurements show a similar phenomenon on clear days as well, but these complications are often ignored. The following expression for diffuse irradiance on the photovoltaic module

$$I_{dt} = CI_b\left(\frac{1+\cos\Sigma}{2}\right) \qquad (13)$$

where C is a sky diffuse factor and a convenient approximation is a follows :

$$C = 0.095 + 0.04\sin\left[\frac{360}{365}(n-100)\right] \qquad (14)$$

F. Reflected Solar Irradiance

The final component of irradiance striking a photovoltaic module results from radiation that is reflected by surfaces in front of the module. The simplest model assumes a large horizontal area in front of the module, with a reflectance ρ that is diffuse, and it bounce the reflected irradiance in equal intensity in all direction. The following expression for reflected irradiance on the photovoltaic module

$$I_{rt} = \rho\, I_b(\sin\beta + C)\left(\frac{1-\cos\Sigma}{2}\right) \qquad (15)$$

III. Result And Discussion

A. Tilt Angle of PV Module

The tilt angle of PV module was calculated using (2) to (4) for a year. The first, the solar declination δ was calculated for 365 days in a year and latitude of Perlis is $6^0\ 29^{'}$ N substituted in (2), finally the tilt angle Σ could be calculated using (3). The tilt angle of PV module in Perlis, Malaysia is shown in Fig. 6.

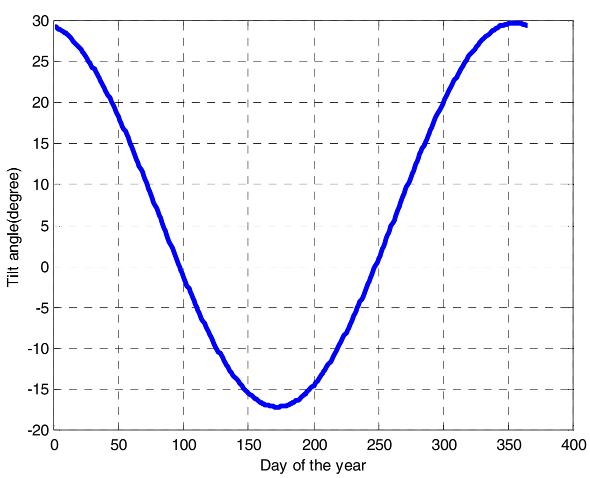

Figure 6. The tilt angles of PV module in Perlis, Malaysia

The tilt angle has positive degree which indicates that the PV module surface facing south, negative degree indicates that it facing north and zero degree indicates that it on horizontal surface [9].

Fig. 6 shows that the tilt angle is as sinusoidal waveform which shifted to left and its value can be divided to three parts, exactly positive, zero and negative. From the 1st January to the 6th April, the tilt angles of PV module in Perlis are positive (29.30^0 on the 1st January and 0.30^0 on the 5th April) which indicate that the PV module facing south. For the 7th April and the 5th September, the tilt angles are 0^0 which indicate that the PV module is on the horizontal surface. From the 8th April to the 4th September, the tilt angle are negative (-0.4776^0 on the 7th April and -0.26^0 on the 4th September), maximum negative is -17.16^0 on the 21st June which indicate that the PV module facing north. From the 6th September to the 31 December, the tilt angles are positive (0.52^0 on the 6th September and 29.44^0 on the 31 December), maximum positive is 29.74^0 on the 22sd December which indicate that the PV module facing south.

B. Solar Irradiance on Tilt Angle of PV Module

The effect of tilt angle of PV module on solar irradiance was calculated using (1) and (5 to (15) for a year. The clear sky global solar irradiance on tilt angles of PV module is shown in Fig. 7. The clear sky global solar irradiance is around 991.47 W/m^2 to 1120.20 W/m^2 which indicate that the sky in Perlis is clear and very high for a year. It indicates that the global solar irradiance in Perlis gives potential for PV power generation [10].

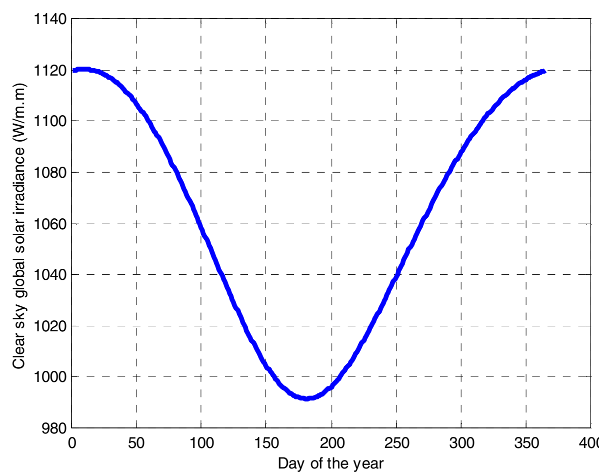

Figure 7. Clear sky global solar irradiance on tilt angles of PV module

Fig. 8 shows 3-dimensional diagram of global solar irradiance as function of both day of the year and tilt angles. When the tilt angles of PV module are positive (the 1st January to the 6th April and the 6th September to the 31st December), the global solar irradiance around 1038 W/m^2 to 1120 W/m^2, the minimum and maximum global solar irradiance happen on the 6th September and on the 1st January, respectively. When the tilt angle of PV module is zero (the 7th April and the 5th September), the solar irradiance is around 1062 W/m^2. When the negative tilt angles of PV module (the 8th April to the 4th September), the minimum and maximum solar irradiance are 991.5 W/m^2 on the 28 June and 1061 W/m^2 on 8th April, respectively. For one year, on the 28 June and -17^0 of tilt angle the solar irradiance is minimum (991.5 W/m^2).

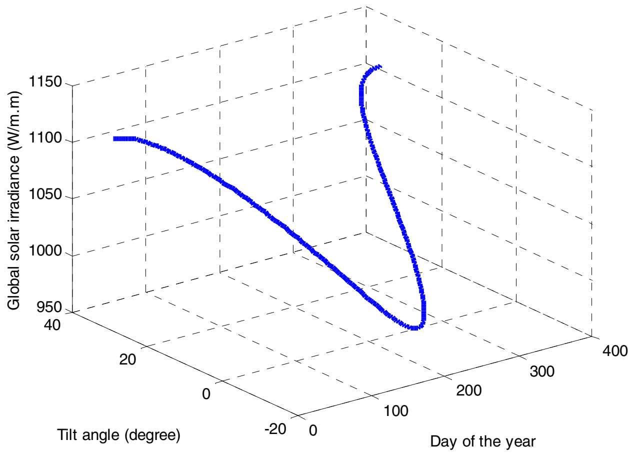

Figure 8. *3-dimensional diagram of global solar irradiance as function of both day of the year and tilt angle*

The average monthly beam, diffuse, reflected and global solar irradiance on tilt angles of PV module are shown in Fig. 9.

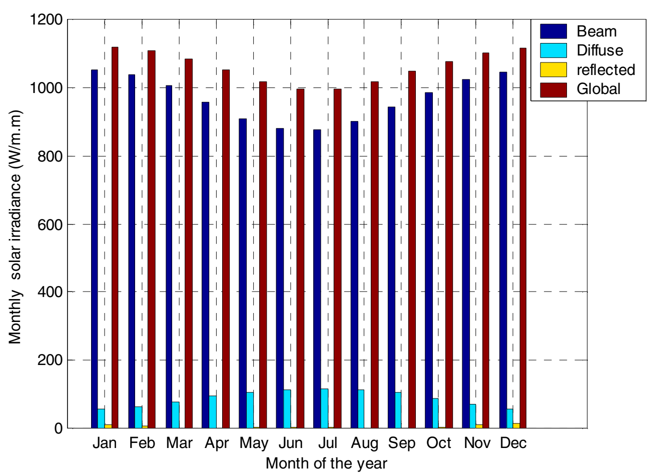

Figure 9. Average monthly beam, diffuse, reflected and global solar irradiance on tilt angles of PV module

Based on part of average monthly clear sky global solar irradiance as shown in Fig. 9, the beam solar irradiance gives a highest value compared with the diffuse and reflected solar irradiance. The average monthly global, beam, diffuse and reflected solar irradiance of a year are 1061 W/m^2 , 968.36 W/m^2 , 88.22 W/m^2, and 4.70 W/m^2, respectively. Percentage of beam, diffuse and reflected of the global solar irradiance are 91.27%, 8.31% and 0.4%. The reflected portion is very low, based on [11] it is often ignored. These data show that the global solar irradiance can be used for certain application, especially in PV power generation.

The minimum, maximum and average monthly global solar irradiance on tilt angles of PV module are shown in Fig. 10.

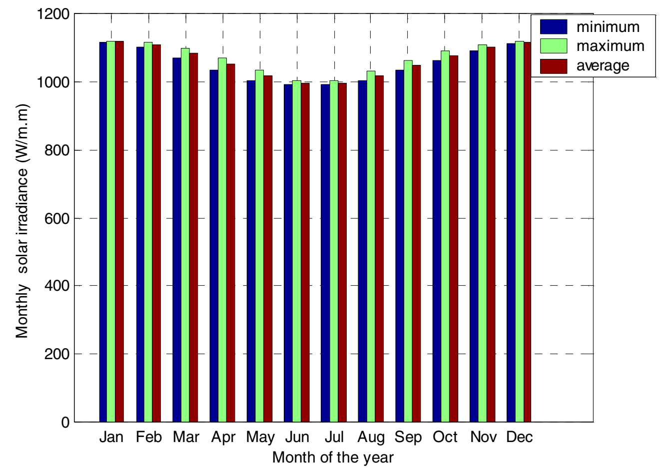

Figure 10. Minimum, maximum and average monthly global solar irradiance on tilt angles of PV module

Based on solar irradiance of a year, Perlis has a big solar irradiance potential, its average is 1061 W/m^2. The highest average monthly global solar irradiance is 1120 W/m^2 on January and its lowest is 995.38 W/m^2 on July. The minimum and maximum monthly solar irradiance are 995.38 W/m^2 on July and 1120 W/m^2 on January, respectively. These data show that the solar irradiance can be used for certain application, especially in PV power generation.

IV. CONCLUSSION

The tilt angles of PV module effect on the solar irradiance that fall on its surface. The tilt angles of PV module in Perlis, Northern Malaysia are -17.16^0 to 29.74^0. The positive, zero and negative tilt angles indicate that the PV module is facing south, on horizontal surface and north, respectively.

The monthly average beam solar irradiance give a highest value compared with the diffuse and reflected solar irradiance. The average monthly beam solar irradiance of a year is , 968.36 W/m^2 , diffuse and reflected solar irradiance are 88.22 W/m^2 , and 4.70 W/m^2 , respectively. Based on global solar irradiance of a year, Perlis has a big global solar irradiance potential, its average is 1019 W/m^2. These data show that the global solar irradiance can be used for certain application, especially in PV power generation.

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