2.21 Solar Radiation on a Tilted Surface

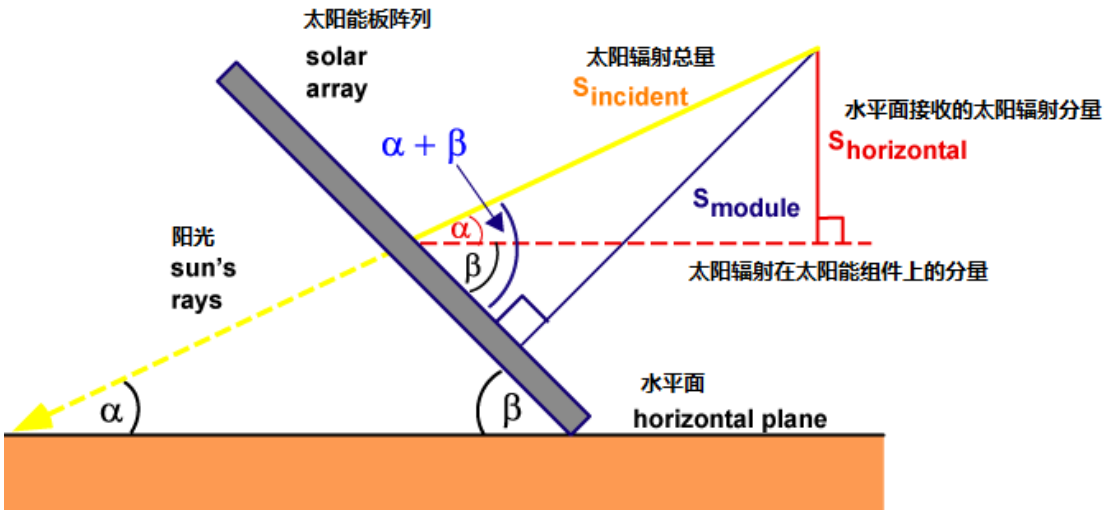
斜面上的太阳辐射

The power incident on a PV module depends not only on the power contained in the sunlight, but also on the angle between the module and the sun. When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight (in other words, the power density will always be at its maximum when the PV module is perpendicular to the sun). However, as the angle between the sun and a fixed surface is continually changing, the power density on a fixed PV module is less than that of the incident sunlight.

入射到光伏组件上的功率不仅取决于入射阳光所具有的功率，也取决于组件与太阳之间的夹角。当吸收面和阳光方向垂直时，吸收面所接收的功率密度与阳光的功率密度相同（也就是说，当吸收面和阳光方向垂直时，功率密度最大）。然而，阳光与固定的表面之间的夹角是在不断变化的，这就导致入射到固定光伏组件上的功率密度小于入射阳光的功率密度。

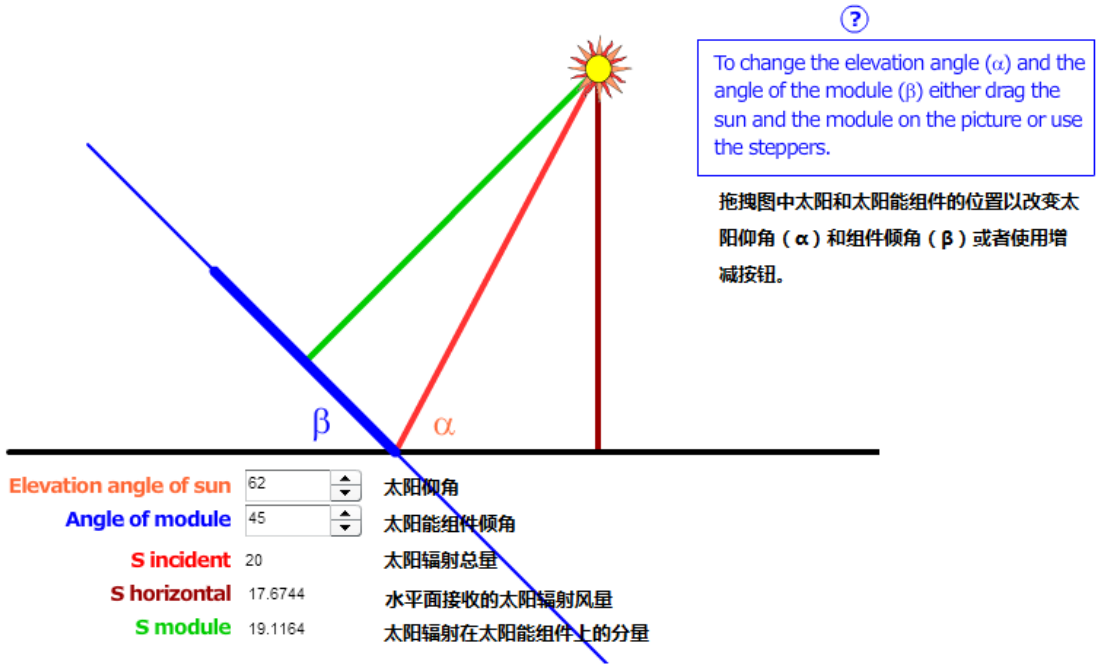
The amount of solar radiation incident on a tilted module surface is the component of the incident solar radiation which is perpendicular to the module surface. The following figure shows how to calculate the radiation incident on a tilted surface (S_{module}) given either the solar radiation measured on horizontal surface (S_{horiz}) or the solar radiation measured perpendicular to the sun ($S_{incident}$).

入射到倾斜放置的组件表面的太阳辐射是太阳辐射总量中与组件平面垂直的分量。下图给出了通过水平面接收的太阳辐射分量（S_{horiz}）或太阳辐射总量（$S_{incident}$）来计算入射到倾斜组件表面的太阳辐射（S_{module}）的方法。



Tilting the module to the incoming light reduces the module output.

沿着阳光入射方向倾斜放置组件会减少组件的输出。



The animation shows the calculation of the various insolations. In each case the length of the vector gives the relative intensity of the radiation.

上图中的动画（译者注：只在原文有效）描绘了如何计算不同的太阳辐射。图中向量的长度代表了太阳辐射的相对值。

The equations relating S_{module}, S_{horiz} and $S_{incident}$ are:

$$S_{horizontal} = S_{incident} \sin \alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

where

α is the elevation angle; and

β is the tilt angle of the module measured from the horizontal.

联系S_{module}，S_{horiz}和$S_{incident}$的公式为

$$S_{horizontal} = S_{incident} \sin \alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

公式中

α表示太阳仰角

β表示组件相对于水平面的倾角

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The elevation angle has been previously given as:

$$\alpha = 90 - \varphi - \delta$$

where φ is the latitude; and

δ is the declination angle previously given as:

$$\delta = 23.45° \sin\left[\frac{360}{365}(284 + d)\right]$$

where d is the day of the year. Note that from simple math $(284 + d)$ is equivalent to $(d - 81)$ which was used before. Two equations are used interchangeably in literature.

之前已经给出了太阳仰角的计算公式

$$\alpha = 90 - \varphi - \delta$$

公式中φ表示纬度，δ表示太阳倾角，可以通过下面的公式计算

$$\delta = 23.45° \sin\left[\frac{360}{365}(284 + d)\right]$$

公式中的d表示某一天在一年中的序数。注意：经简单数学推导就可以知道此处给出的$(284 + d)$与之前的公式中给出的$(d - 81)$是等效的。在文献中，这两个公式是可互换的。

From these equations a relationship between S_{module} and S_{horiz} can be determined as:

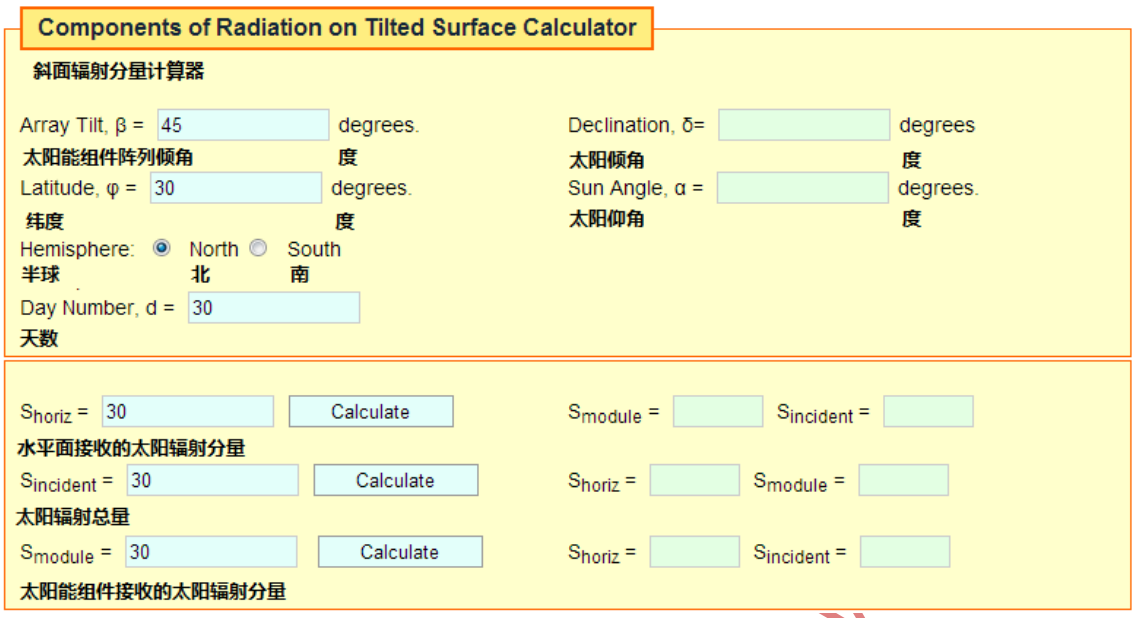
$$S_{module} = \frac{S_{horizontal} \sin(\alpha + \beta)}{\sin \alpha}$$

从上面的公式，我们可以得出S_{module}和S_{horiz}之间的关系为：

$$S_{module} = \frac{S_{horizontal} \sin(\alpha + \beta)}{\sin \alpha}$$

The following active equations show the calculation of the incident and horizontal solar radiation and that on the module. Enter only one of S_{module}, S_{horiz} and $S_{incident}$ and the program will calculate the others.

下面的活动公式给出了计算太阳辐射总量、水平面接收的太阳辐射分量以及太阳辐射在组件斜面上的分量。只需输入S_{module}、S_{horiz}和$S_{incident}$中的一项，程序会计算另两项。



The tilt angle has a major impact on the solar radiation incident on a surface. For a fixed tilt angle, the maximum power over the course of a year is obtained when the tilt angle is equal to the latitude of the location. However, steeper tilt angles are optimized for large winter loads, while lower title angles use a greater fraction of light in the summer. The simulation below calculates the maximum number of solar insolation as a function of latitude and module angle.

组件倾角对于其表面接收的太阳辐射有很大影响。当组件倾角固定时，如果其角度等于该地点的纬度则能够获得一年中的最大功率。然而，如果冬季的能耗较多，就需要提高倾角。如果夏季能耗较多，就需要降低倾角。下面的仿真可以计算受纬度和组件倾角影响的最大太阳辐射。

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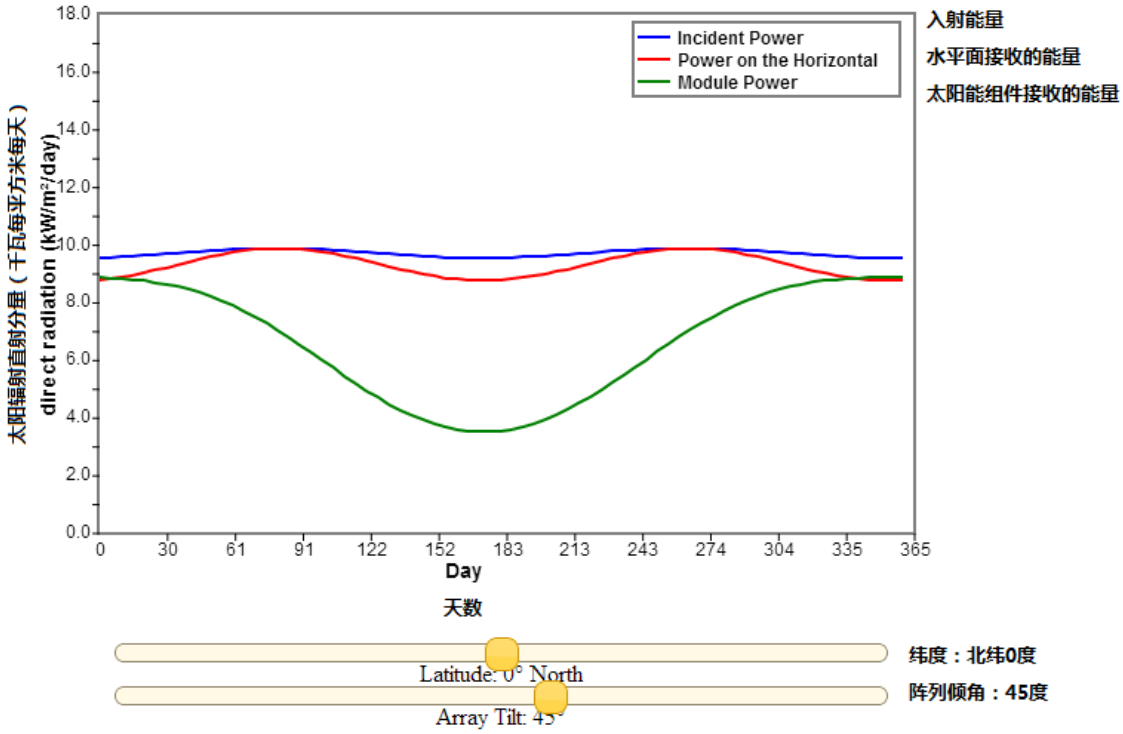

The effect of latitude and module tilt on the solar radiation received throughout the year in W.h.m-2.day-1 without cloud. On the x-axis, day is the number of days since January 1. The Module Power is the solar radiation striking a tilted module. The module tilt angle is measured from the horizontal. The Incident Power is the solar radiation perpendicular to the sun's rays and is what would be received by a module that perfectly tracks the sun. Power on Horizontal is the solar radiation striking the ground and is what would be received for a module lying flat on the ground. These values should be regarded as maximum possible values at the particular location as they do not include the effects of cloud cover. The module is assumed to be facing south in the northern hemisphere and north in the southern hemisphere. For some angles, the light is incident from the rear of the module and in these cases the module power drops to 0.

上面的仿真给出了当没有云层影响时，一年中的太阳辐射（单位：瓦每平方米每天）受纬度和组件倾角的影响情况。在 X 轴上，天数上表示一天在一年中的序数（以 1 月 1 日为第 1 天），组件功率表示入射到倾斜组件上的功率。组件倾角是它与水平方向的夹角。入射功率指的是与太阳方向垂直的太阳辐射，即通过组件实现完全的太阳跟踪时所接收到的太阳辐射。水平功率指的是入射到地面的太阳辐射，即当组件平放在地面上时所接收到的太阳辐射。这些功率都是对于某一个地点可能的最大值，因为没有考虑云层覆盖的影响。我们假设北半球的组件朝向南边，南半球的组件朝向北边。对于一些角度，阳光会来自于组件的背面。在这些情况下，组件功率为 0。

As can be seen from the above animation, for a module tilt of 0°, the Module Power and Power on Horizontal are equal since the module is lying flat on the ground. At a module tilt of 80°, the module is almost vertical. The Module Power is less than the Incident Power except when the module is perpendicular to the sun's rays and the values are equal. The

module is orientated to the equator so it faces north in the Southern Hemisphere and south in the Northern Hemisphere. As module moves from the Northern to Southern Hemisphere (latitude = 0°), the module is turned to face in the opposite direction and so the Module Power curve flips. When the light is incident from the rear of the module the Module Power drops to zero. Try setting the latitude to your location and then varying the module tilt to see the effect on the amount of power received throughout the year.

从上面的动画可以看出，对于倾角为 0 度的组件，因为组件平放在地面上，组件功率和水平功率是相等的。当组件倾角为 80 度时，组件几乎就是竖直放置的。除了组件与阳光方向垂直这种情况外，组件功率一般都小于太阳辐射总功率。组件是朝着赤道放置的，因此在南半球的组件朝北，在北半球的组件朝南。当组件的位置从北半球移动至南半球时，组件的朝向发生翻转，因此组件功率曲线对称翻转。当光线从组件背面入射时，组件功率降为 0。可以尝试把纬度设定为你所在地点，而后改变组件倾角以观察倾角对一年中接收的功率的影响。

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