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A Method of Array Configuration for Tracking Photovoltaic Devices

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Abstract

A new method of array configuration for solar tracking photovoltaic (PV) devices is proposed. By analyzing the affecting factors of shadows, a calculation model of PV cell panels' shadow in the sunlight is structured. And the variation rule of shadows in a year is founded by simulation program. Then a spacing calculation method of the solar tracking device array is proposed. The experiment result shows that the proposed method can minimize the installation spacing of PV device by ensuring PV cell panels without shadow shading and save area effectively in PV power station construction.

Keywords: *solar tracing photovoltaic device, cell panel, shadow, PV array configuration, 3D graphics transformation*

1. Introduction

The configuration of photovoltaic (PV) devices will determine the generating capacity, material consumption and the area in the construction of PV power station. Fixed PV devices used to be adopted in the early time. The method of array configuration for such devices is simple and ripe [1-3]. In recent years, in order to increase the receiving quantity of solar energy, the solar tracking PV devices are developing quickly and widely used. Compared with the fixed PV devices, it can improve the receiving quantity up to 10-45% [4]. But the current configuration method for tracking PV devices has rarely been reported. Literature [5] puts forward an array spacing configuration method for tracking PV devices with single axis. But the method doesn't analyze the variation rules of the cell panel's shadows in a year. So the result of array spacing configuration is too large to save lands and materials in construction of PV power station.

There are three main factors influencing the array spacing configuration. The first is shadow shading between adjacent cell panels. The second is maintenance channels for the PV device when it doesn't work. The third is a space for ventilation and heat dissipation in the process of power generation. Among the three factors, the shadow shading between adjacent cell panels is the most important factor which can cause a lot of energy loss and even make PV cells abandoned [6]. Experience shows that the array spacing configuration according to the shadow shading factor can meet the other factors. Therefore, avoiding the shadow shading between adjacent cell panels becomes the decisive factor of PV array configuration. The cell panels of tracking PV device always rotate following the sun. So the PV array spacing can be determined by the threshold position between the adjacent cell panels without shadow shading in a year. The proposed method starts from mechanism of the shadow formation. Then the shadow position calculation model for PV cell panel under the sun will be built by 3D graphics transformation. By the model we can summarize the shadow variation rules of tracking cell panels using computer simulation techniques. And the array spacing configuration method for tracking PV devices will be proposed.

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2. The Calculation Model of Cell Panel's Shadow Position

As shown in Figure 1, the shadow is formed by at least three factors which are sunlight λ, projection plane π and object *P*. When an object is under the irradiation of light and blocks the object (plane π) behind it, the shadow will be generated. According to these factors, the calculation model of shadow position can be built by 3D graphics transformation.

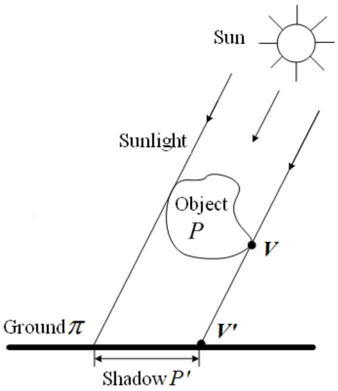


Figure 1. The Formation of an Object Shadow

Based on the description of the *horizontal coordinate system* in theory of celestial sphere, the position of the sun is determined by its elevating angle Hs and azimuth angle As . The angles can be calculated in literatures [7, 8]. If we can convert the angles to a direction vector, Hs and As can be calculated in matrix form. Set the direction vector of the sun to be $\boldsymbol{S}=[S_x,S_y,S_z]$. According to the relation between *spherical coordinate system* and *right angle coordinate system*, the direction vector of $\boldsymbol{S}$ can be obtained. Then it can be normalized into a unit vector as equation (1).

$$\begin{cases} S_x=\cos(Hs)\cdot\sin(As) \\ S_y=\sin(Hs) \\ S_z=\cos(Hs)\cdot\cos(As) \end{cases} \tag{1}$$

The equation of ground π can be described through *dot method*. Set it to be $N_x\times x+N_y\times y+N_z\times z+N_w=0$, and $\boldsymbol{N}=[N_x,N_y,N_z]$ is the normal vector of the ground. N_w is a constant. According to the projecting transformation matrix [9], the shadow transformation matrix which describes the shadow of an object under the sun can be built as equation (2).

$$\boldsymbol{M}=\begin{bmatrix} NySy+NzSz & -NySx & -NzSx & -NwSx \\ -NxSy & NxSx+NzSz & -NzSy & -NwSy \\ -NxSz & -NySz & NxSx+NySy & -NwSz \\ 0 & 0 & 0 & NxSx+NySy+NzSz \end{bmatrix} \tag{2}$$

In addition, the cell panel of tracking PV device rotates around the endpoint of frame. The movement can be described by rotation transformation matrix. Set $\boldsymbol{R}_X$, $\boldsymbol{R}_Y$ and $\boldsymbol{R}_Z$ respectively to be the matrixes which describe the points rotating around the X, Y and Z axis [10]. Then a composite matrix $\boldsymbol{R}=\boldsymbol{R}_X\cdot\boldsymbol{R}_Y\cdot\boldsymbol{R}_Z$ is gotten, which can express any rotation movement.

The cell panel is made up of many pieces of rectangular PV cells. Its shape is always polygon. We only need to make rotation and projection transformation on the all boundary points such as $\boldsymbol{V}$ to get the projecting point $\boldsymbol{V'}$ in Figure 1. Then by connecting the projection points, we can draw the shadow shape. Above all, the calculation model of tracking PV device is described as equation (3).

$$\boldsymbol{V'} = \boldsymbol{M} \cdot \boldsymbol{R} \cdot \boldsymbol{V} \tag{3}$$

3. The Variation Rules of Cell Panel's Shadows

In order to avoid shadow shading between adjacent cell panels, it is necessary to know the variation rules of cell panels' shadows and measure the array spacing between the PV devices. Figure 2 is a 3D model of a tracking PV device with inclined single axis rotating, and A ~ H are boundary points of the cell panel. We can find the variation rules of the cell panel's shadows in a year by calculating the shadow position in simulation program. The progress can be carried out from the following two parts.

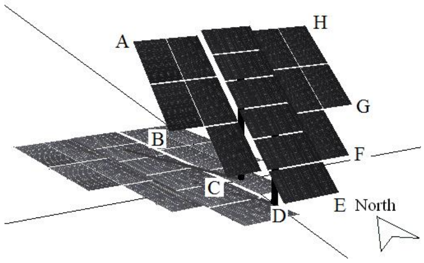


Figure 2. 3D Model of a Tracking PV Device with Inclined Single Axis Rotating

(1) The variation rules of the shadow throughout a day

Take a day (*e.g.*, Feb. 21), calculate and draw the cell panel's shadow positions every 30 minutes from the beginning to the ending running time in a day. The results are shown in Figure 3. It can be concluded that the shadows are symmetrical by twelve o'clock in a day. The projecting position of the shadow is farthest at the beginning and the ending time.

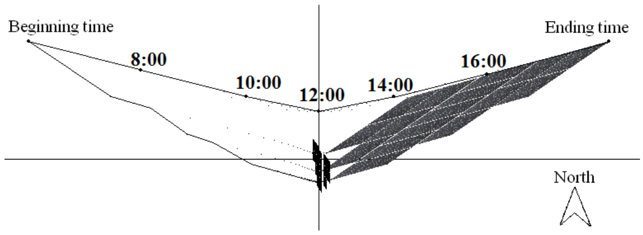


Figure 3. Variation of the Shadows Throughout a Day

(2) The variation rules of the shadow throughout a year

The earth rotates by itself. It also moves around the sun. So the shadow of object will vary not only in a day, but also in different seasons of a year. With the combination of the conclusion in part (1), we can select the beginning running time (*e.g.*, 8 a.m.) to calculate and draw the shadow positions of boundary points in a year. Results are shown in Figure 4.

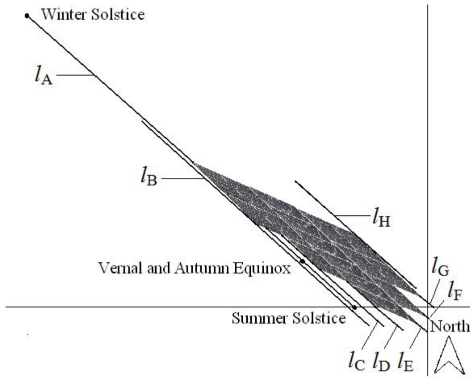


Figure 4. Variation of the Shadow at 8 a.m. Throughout a Year

In Figure 4, lA ~l H are trace lines of the shadow for boundary points. It can be seen that they are straight line and parallel each other. The shadow of the cell panel is along within the two most lateral trace lines in a year. And the shadow is shortest on summer solstice. And it varies to be longest on winter solstice. As the year goes on, the regular rules cycle.

4. The Method of Array Configuration for Tracking PV Device

The efficiency of the PV cell panels will reduce if the adjacent cell panels are shaded by the shadow. In order to get the minimum array spacing, the threshold position of a shadow can be calculated by its variation rules when the adjacent panels don't produce shadow shading. The research of part(2) shows that the shadow at the beginning running time every day throughout a year is along within the most lateral trace lines of the boundary points. Therefore, the minimum array spacing for tracking PV devices can be calculated by drawing the most lateral trace lines of the boundary points at the beginning running time in a year.

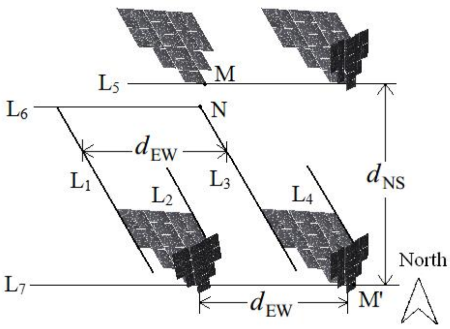


Figure 5. Calculation of PV Array Spacing

As shown in Figure 5, L_1 and L_2 (or L_3 and L_4) are respectively the most lateral trace lines of east-west adjacent devices. M and M' are the southernmost points of trace lines of north-south devices. N is the northernmost point. L_5, L_6 and L_7 are respectively parallel straight line to the east-west through point M, N and M'. Obviously, d_{EW} shows the east-west adjacent devices' space which is equivalent to the east-west distance from L_1 to L_3 (or L_2 to L_4). It will be minimized when L_2 just overlaps L_3. Similarly, d_{NS} shows the north-south adjacent devices' space which is equivalent to the north-south distance between L_5 and L_7. It will be minimized when L_5 just overlaps L_6.

In conclusion, the optimal configuration of array spacing for tracking PV devices is simplified into a computation of a single device's shadow positions. Set f_E and f_W

respectively to be the equations of a single device's east-west lateral trace line. Therefore the east-west difference d_{EW} is the minimal array space for east-west adjacent devices as equation (4). In the same way, set $N_{\max}$ and $S_{\max}$ to be the location of the northernmost and southernmost points of all trace lines. Then the difference d_{NS} is the minimal array space between north-south adjacent devices as equation (5).

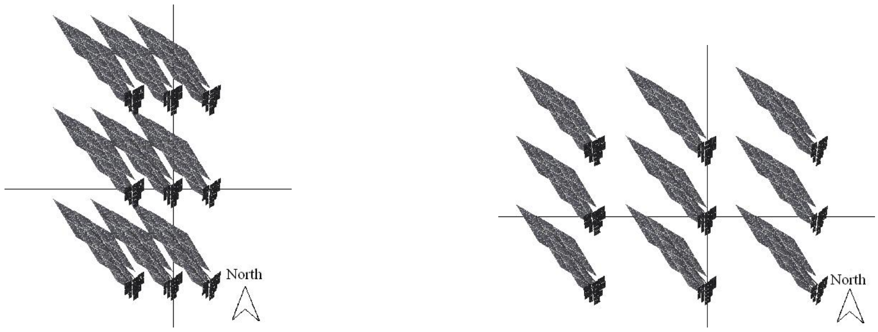
$$d_{\mathrm{EW}} = f_{\mathrm{E}} - f_{\mathrm{W}} \tag{4}$$

$$d_{\mathrm{NS}} = S_{\max} - N_{\max} \tag{5}$$

5. Simulation and Result

In order to verify the validity of the proposed method, a simulation is conducted to calculate the PV array spacing. A solar tracking PV power station is built in Dunhuang of Gansu Province in China, where locates in 40.1° N and 94.7° E. The power station adopts tracking devices with inclined single axis rotating whose maximum length of the cell panel in the north-south and east-west are 6.214m and 5.794m. And a pillar of the cell panel is 3.728m high. It is fixed towards the south with the tilt angle of 35°.

The condition in PV array configuration is to ensure that there is no shadow shading between cell panels in running time of 6 hours which is the *true solar time* between 9:00a.m and 15:00p.m. The array spacing in east-west and north-south which are calculated by the proposed method are respectively 8.4m and 20.5m. Likewise, the results by literature [5] are 24.8m and 15.5m. The areas of two methods are respectively $172.2\,\mathrm{m}^2$ and $384.4\,\mathrm{m}^2$. Based on two sets of data, a 3×3 PV array is established. And the contrast results are shown in Figure 6. It can be seen that there is no shadow shading between the panels using two methods on winter solstice when the shadow is the longest in a year. On the contrast, the area which is configured by the proposed method will be decreased by 55.2%.



(a) Configuration using new method (b) Configuration using method of [5]

Figure 6. Comparing of Configuration at 9:00 a.m. on Winter Solstice

6. Conclusion

In order to find the variation rules of shadow for tracking PV devices, the shadow calculation model has been built. And a new method of computing the PV array spacing is proposed. It can configure the minimal space without shadow shading between the adjacent cell panels on running time. It is effective in saving the area of single device and improving the installed capacity. However, the method is unsuitable for the region undulating terrain.

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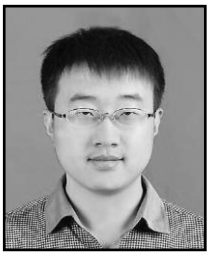

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