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Analysis of the influence of shading by horizon of PV cells on the operational parameters of a photovoltaic system

Abstract. *The work presents the components of solar radiation that reaches the horizontal plane and a method of determining the energy value of the radiation that reaches the surface of a photovoltaic receiver inclined to the ground line at a certain angle. A shading assessment diagram and a methodology for determining the vertical angles and the influence of the horizon on the shading of a PV receiver were provided. A method of determining the direct radiation correction factor depending on the horizon line was presented. The influence of light shading on the current and voltage characteristics of a solar module was determined.*

Streszczenie. *W pracy przedstawiono składowe promieniowania słonecznego docierającego do powierzchni horyzontalnej oraz sposób wyznaczenia wartości energii promieniowania padającej na powierzchnię odbiornika fotowoltaicznego nachylonego pod pewnym kątem do ziemi. Zamieszczono diagram oceny cieniowania oraz metodykę wyznaczenia kątów pionowych i wpływu horyzontu na cieniowanie odbiornika PV. Przedstawiono sposób wyznaczania współczynnika korekcyjnego promieniowania bezpośredniego wywołanego linią horyzontu. Określono wpływ słabego cienia na charakterystykę prądowo-napięciową modułu solarnego. (**Analiza wpływu cieniowania ogniw PV przez horyzont na parametry pracy systemu fotowoltaicznego**).*

Keywords: correction factor, shading, horizon, PV receiver, direct radiation
Słowa kluczowe: współczynnik korekcyjny, zacienienie, horyzont, odbiornik PV, promieniowanie bezpośrednie

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Introduction

Total solar radiation G that reaches a horizontally situated receiver is the sum of direct radiation G_B and diffuse radiation G_D. Sometimes also radiation reflected by the surface G_R which is of derivative character as it constitutes part of direct radiation and it has no distinguished direction is included. Thus, total energy of solar radiation H, which reaches the horizontal surface of the receiver is a component of direct radiation energy H_B and diffuse radiation energy H_D. The dependencies are expressed in formulas 1 and 2 [1],[2],[4]:

$$G = G_B + G_D \quad (1)$$

$$H = H_B + H_D \quad (2)$$

In the case of a receiver inclined at the angle β to the horizontal plane, the value of power density of solar radiation G_G *and the energy* H_G that reach the receiver are expressed with dependencies 3 and 4 [1],[2]:

$$G_G = G_{GB} + G_{GD} + G_{GR} \quad (3)$$

$$H_G = H_{GB} + H_{GD} + H_{GR} \quad (4)$$

In accordance with the Liu-Jordan theory, the total value of power density of solar radiation and the energy that reaches the surface of a receiver inclined at the angle β is expressed with formulas 5 and 6 [2],[4]:

$$G_G = R_B \cdot G_B + R_D \cdot G_D + R_R \cdot \rho \cdot G_R \quad (5)$$

$$H_G = R_B \cdot H_B + R_D \cdot H_D + R_R \cdot \rho \cdot H_R \quad (6)$$

where: R_B, R_D, R_R – correction factors for direct radiation, diffuse radiation, and reflected radiation.

Due to the fact that the majority of radiation that reaches the surface of the receiver is direct radiation, this type of radiation is considered as the most important in the process of determining the total value of the solar energy which will be converted to electric energy by the PV receiver in the process of photovoltaic conversion. The value of the energy is, thus, expressed with formula 7 [1],[2]:

$$H_{GB} = R_B \cdot H_B = R_B \cdot (H - H_D) \quad (7)$$

The energy of solar radiation on the horizontal plane can be distributed to particular hours of the day. Thanks to that, it is possible to determine the correction factor for direct radiation depending on the horizon shading, with the use of the pattern of the Sun's path for every month which is a shading diagram for the appropriate latitude. A sample shading diagram for the latitude of 53°N (central Poland) is presented on figure 2. Every point on the average monthly radiation diagram corresponds with a specific portion of daily direct radiation in accordance with the appropriate assessment pattern. In order to use the shading diagram, it is necessary, first of all, to mark the solar generator in the orientation γ as a vertical line. Next, it is necessary to mark the horizon line in relation to which the PV receiver is situated. Using the shading assessment diagram, the total weight value ΣGPS is determined for all the points situated on the Sun's path for the appropriate months (often only for a few winter months [1],[3],[4].

Determination of the shading level

A. Shading assessment diagram

Depending on the positioning of the photovoltaic receiver in relation to the south, when the azimuth angle is 0º, different point weight values are assumed from 3% to 1%, as presented on figure 1. The weight value of 3% is assumed for the deviation value of $0º < |\Delta\gamma_s| \le 30º$, 2% for $30º < |\Delta\gamma_s| \le 60º$, and 1% for $60º < |\Delta\gamma_s| \le 80º \div 110º$ depending on the inclination angle of the receiver surface β to the horizontal plane. Thus, for example, for a receiver inclined at the angle of 60°, the weight factor 1% is assumed for the deviation value of $60º < |\Delta\gamma_s| \le 85º$, and for a receiver inclined at the angle of 30° for the deviation value of $60º < |\Delta\gamma_s| \le 100º$ [1].

In order to determine the level of energy losses due to shading, the appropriate weight should be assumed for every point situated below the horizon line, in accordance with the shading assessment diagram. The sum of all the weight percentage values for the shaded points situated below the horizon line in particular months constitutes the total weight $\sum GPB$ for the shaded points.

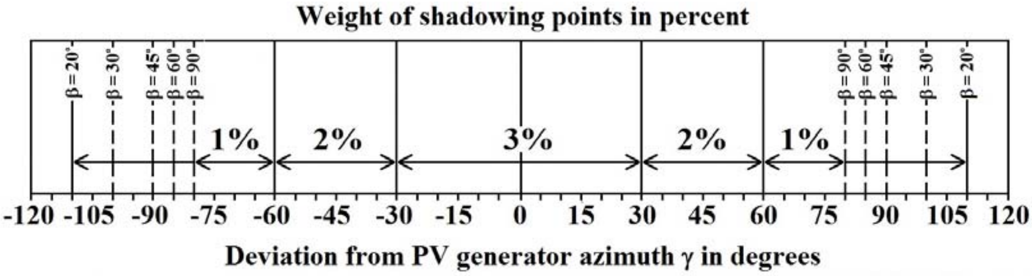

Fig. 1. Assessment diagram for a shading diagram [1]

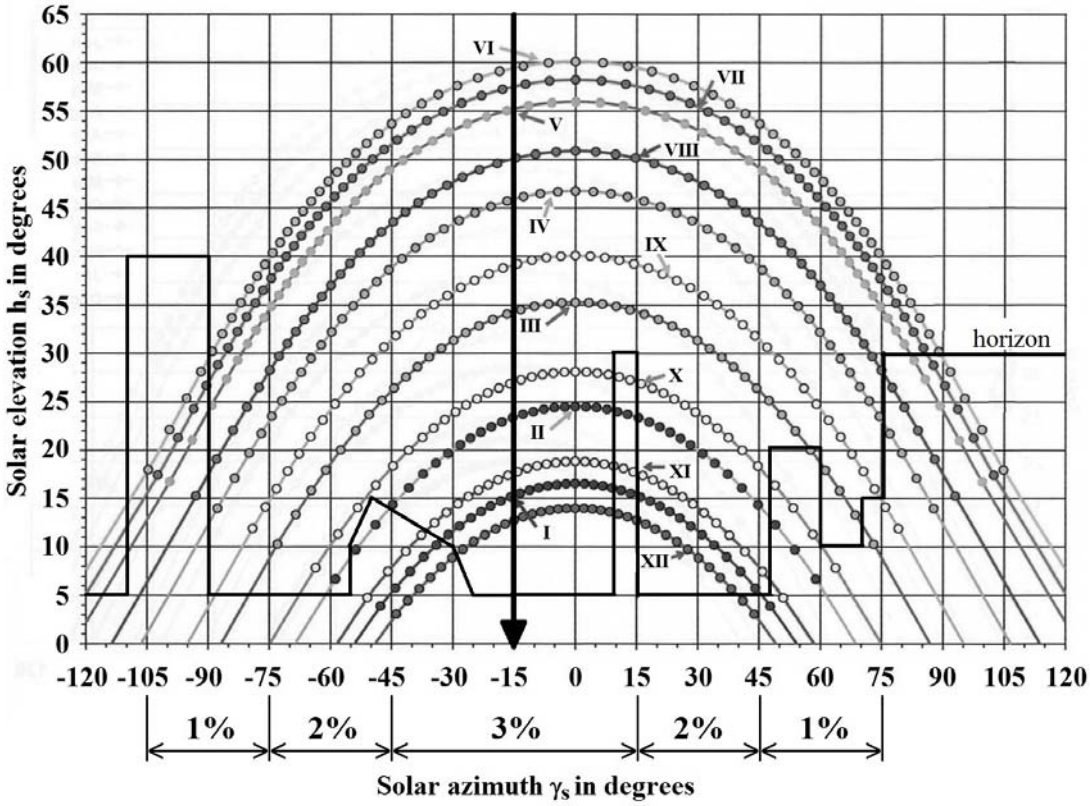

Fig. 2. Shading diagram and weight of shadowing points for 53°N [1]

B. Shading correction factor

Having the ∑*GPS* and ∑*GPB* values, it is possible to determine the shading correction factor k_B for the months considered with the use of the formula 8 [1]:

$$k_B = 1 - \frac{\sum GPB}{\sum GPS} \qquad (8)$$

where: ΣGPB – total weight for the shaded points along the Sun's path for the selected month, ΣGPS – total weight for all the points along the Sun's path for the selected month.

The factor assumes values in the range from 0 (complete shading) to 1 (lack of any shading).

Example of calculation of k_B

The subject of the analysis was a solar generator located in central Poland (the latitude of 53ºN), with the azimuth angle of γ_s = -15º (deviation towards the west) and with the inclination angle to the ground surface of β = 45º.

In order to determine the horizon line (identify the vertical angles of the objects that can shade the photovoltaic receiver), an inclinometer, whose sample form is presented on figure 3, should be used.

In order to determine the elevation angles (the horizon line), one should position themselves in the location of the PV receiver using a compass and turn to the east. Next, point the inclinometer towards the top of the highest object located there and read the value showed. The same action should be repeated after turning by 5° towards the west. After connecting the points read, the features of the landscape will be reflected forming the horizon line (as presented on figure 2).

Fig. 3. A view of an inclinometer with a compass [5]

After the azimuth of the generator and the horizon line marked on the shading diagram for the appropriate latitude (as shown on figure 2), it is possible to identify the months for which the shading correction factors should be determined.

In the case presented, the correction factor is not determined only for the months of April and September, as ΣGPB=0, that is $k_B = 1$. For the remaining months, its values were determined in accordance with the example presented for the month of January (equations 9-11). All the values are presented in table 1.

(9) $$\sum GPS = 24\cdot 3\% + 12\cdot 2\% + 1\cdot 1\% = 97\%$$

(10) $$\sum GPB = 6\cdot 3\% + 1\cdot 2\% + 1\cdot 1\% = 21\%$$

(11) $$k_B = 1 - \frac{\sum GPB}{\sum GPS} = 1 - \frac{0{,}21}{0{,}97} = 0{,}78$$

Table 1. The values of the shading correction factor

Month	ΣGPS [%]	ΣGPB [%]	k_B [-]
I	97	21	0,78
II	97	13	0,87
III	101	2	0,98
IV	101	0	1,00
V	100	2	0,98
VI	99	4	0,96
VII	002	4	0,96
VIII	105	2	0,98
IX	104	0	1,00
X	100	10	0,90
XI	95	20	0,79
XII	100	31	0,69

The determined values of the shading correction factor reflect the energy value of the direct radiation flux that reaches the solar receiver, considering horizon shading.

(12) $$H_{GB} = k_B \cdot R_B \cdot H_B = k_B \cdot R_B \cdot (H - H_D)$$

After applying the values of the correction factor determined in formula 7 used to calculate the amount of direct radiation energy on an inclined surface, a modified form of formula 12 is obtained [1].

Influence of shading on the current – voltage characteristic of a PV module

Light shading caused by landscape elements should not lead to the activation of the bypass diodes in PV panels. As it is presented on figure 4, the voltage value for the maximum power point of a shaded panel (MPP 1) is practically unchanged in comparison to the theoretical value for an unshaded panel (MPP 2).

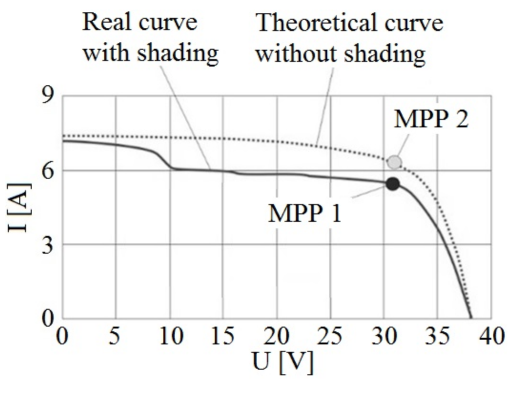

Fig. 4. Current and voltage characteristics of a PV module with and without shading [6]

As a result of light shading, only the current value for the maximum power point decreased. For the module examined with the theoretical power of 190 W, the value of generated power obtained as a result of shading was at the level of 160 W. Thus, light shading of a PV module will result in the decrease of the value of the current flow proportionally to the level of shading. In turn, different current levels in a given module in relation to other modules will result in a decrease of the efficiency of all the modules connected in a given string.

Conclusions

Direct solar radiation which has the greatest influence of the efficiency of PV cells can be limited by landscape features or buildings and, thus, reduce the energy gain from solar batteries. It is important to precisely mark the horizon line on the shading diagram for the particular latitude and to determine the values of the correction factors in order to estimate the values of solar radiation that reaches the surface of the receiver and the energy gain. Otherwise, the radiation value and the gain to be obtained may be overestimated.

REFERENCES

[1] Haberlin H.: "Photovoltaics. System Designed and Practice", John Wiley & Sons Ltd., 2012.
[2] Jastrzębska G.: „Ogniwa słoneczne", Wydawnictwa Komunikacji i Łączności, 2013.
[3] Moyra T., Panua R.: "Building Integrated Photovoltaic (BIPV) system. Solar energy", Lambert Academic Publishing GmbH & Co., 2012.
[4] Sarnik M. T.: "Podstawy fotowoltaiki", Oficyna Wydawnicza Politechniki Warszawskiej, 2008.
[5] http://www.codimex.com.pl/surveymaster_klinometr_kompas_pol, dn. 16.10.2013.
[6] http://solaris18.blogspot.com/2013/07/skutki-sabego-i-silnego-zacienienia.html, dn. 10.10.2013.

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