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# The method of selection of optimum fitting parameters for stationary photovoltaic systems and optimum control parameters for tracking photovoltaic systems

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Summary. The paper presents a simplified method of selection of the optimum fitting parameters for stationary photovoltaic systems and optimum control parameters for tracking photovoltaic systems. The method consists in the stationary analysis of the available files of the database from complete 30-year observations for 43 meteorological stations in Poland. The application of the presented method has been shown on the example the meteorological station located in Płock Trzepowo. Based on the data for the selected station a set of optimum parameters has been developed.

Key words: solar radiation intensity, solar collector, photovoltaic conversion, photovoltaic panel.

## INTRODUCTION

In the paper the authors proposed a simplified method of determining of the optimum parameters for the fitting of stationary photovoltaic systems and determining of the control ranges for tracking photovoltaic systems based on the available meteorological data gathered during long-term observations. The basic criterion when selecting the parameters is the maximum value of the solar radiation hitting the surface of the photovoltaic module [6, 13, 14, 16].

On the web page of the Ministry of Transport, Construction and Maritime Economy (*www.transport.gov.pl*) data files have been made available, generated from the Institute of Meteorology and Water Management that determine the 'typical meteorological years'. The data in these files come from observations carried out in 61 meteorological stations 43 of which have had full data streams from 30-year observations in the years: 1971-2000. 'Typical meteorological years' have been developed based on the EN ISO 15927:4 standard [18].

For the needs of the proposed method, data from the following files have been used: *wmo123600iso.txt* and *wmo123600iso_stat.txt* for the nearest meteorological station located in Płock Trzepowo located at: $52^0$35' N, $19^0$44' E. The data files contain values of solar radiation both total and dispersed for the horizontal plane and the values for the planes of different angles of incidence. The files have been imported and processed through built-in functions of a spreadsheet.

## SELECTION OF THE FITTING PARAMETERS FOR THE STATIONARY PHOTOVOLTAIC SYSTEMS

Theoretical analyses of the optimum angle of incidence $\beta_{opt}$ of the solar radiation receiver in terms of the criterion of the maximum energy benefit have shown a close relation of this angle to the period of operation for which the calculations were carried out [9, 8, 4]. If we take into account only the direct component of the solar radiation then the optimum angle of incidence of the solar collector oriented to the south we can calculate from the dependence [12, 2, 3]:

$$\beta_{opt} = \varphi - \delta, \tag{1}$$

where:

$\phi$ - Latitude assumed as positive for the northern hemisphere,

$\delta$ - Solar declension – angular sun orientation against the plane of the equator at astronomical noon.

The solar declension on a given day we can calculate from the Cooper's approximate formula:

$$\delta = 23,45 \cdot \sin\left(360 \cdot \frac{284 + n}{365}\right), \tag{2}$$

where:

n – consecutive month in the year.

In practice, average value of the solar declension is assumed for the analyzed period of operation. Most often

it is the value of the solar declension for the day recommended in a given month i.e. such a day for which the solar declension equals the average monthly value [11, 5]. Table 1 presents the calculations of the optimum angle of incidence $\beta_{opt}$ for the photovoltaic system, whose plane is oriented to the south. These results take into account only the direct component of the solar radiation. The calculations were made for the latitude $52^0 35'$ N at which the meteorological station Płock Trzepowo is located.

**Table 1.** Results of calculations $\beta_{opt}$ for the location $52^0 35'$ N – Płock Trzepowo

| Month | Solar declension for the recommended day in a given month $\delta$ [$^0$] | Optimum angle of incidence of the surface of the photovoltaic system $\beta_{opt}$ [$^0$] |
|---|---|---|
| I | -20,9 | 73 |
| II | -13,0 | 66 |
| III | -2,4 | 55 |
| IV | 9,4 | 43 |
| V | 18,8 | 34 |
| VI | 23,1 | 29 |
| VII | 21,2 | 31 |
| VIII | 13,5 | 39 |
| IX | 2,2 | 50 |
| X | -9,6 | 62 |
| XI | -18,9 | 71 |
| XII | -23,0 | 76 |

These results have a high error rate because additionally diffusion and reflection components get to the surface of the photovoltaic system [15, 10, 1].

In order to determine the optimum angle o incidence for a stationary photovoltaic system fitted in the plane oriented to the south an analysis has been performed of selected data collected in file *wmo123600iso_stat.txt* for the said station Płock Trzepowo. In the field of the databases values of solar radiation are available for different positions of the plane of the receiver - as schematically presented in fig. 1.

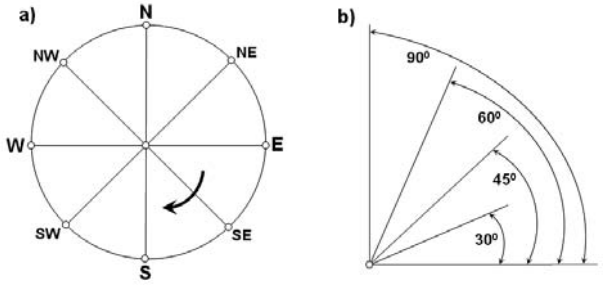


**Fig. 1.** Schematics of different data gathered in the files of the meteorological stations: a) data available for the azimuth position-γ, b) data available for the angle of incidence against horizon-β

Table 2 presents the query for data from the monthly report of the total solar radiation for the meteorological station located in Płock Trzepowo. The greatest values of the solar radiation have been found and presented in individual months for several constant orientations of the plane of the fitting of the radiation receiver. The marking of the receiver plane setting in table 2 is composed of the letter determining the azimuth position and the number determining the angle of incidence against the horizon frequently referred to as the elevation angle as seen in the schematics in figure 1.

**Table 2.** List of greatest monthly values of the total solar radiation for the meteorological station located in Płock Trzepowo

| Month | Orientation for MAX | The total of the monthly solar radiation [Wh×m$^{-2}$] | | | | | |
|---|---|---|---|---|---|---|---|
| | | MAX | S-0 | S-30 | **S-45** | S-60 | S-90 |
| I | S-60 | 28802 | 20395 | 25779 | 27654 | 28802 | 28655 |
| II | S-60 | 42967 | 30207 | 39039 | 41718 | 42967 | 40940 |
| III | S-60 | 86369 | 66187 | 81598 | 85468 | 86369 | 79220 |
| IV | S-45 | 92869 | 86049 | 92757 | 92869 | 90760 | 80643 |
| V | S-30 | 136746 | 131342 | 136746 | 134467 | 128998 | 110993 |
| VI | S-30 | 138354 | 136926 | 138354 | 134864 | 128949 | 112163 |
| VII | SE-30 | 141089 | 137722 | 139657 | 136483 | 130894 | 114754 |
| VIII | S-30 | 121894 | 115339 | 121894 | 120862 | 116985 | 102266 |
| IX | S-45 | 91266 | 80249 | 89763 | 91266 | 90412 | 82022 |
| X | S-60 | 59882 | 45519 | 55905 | 58808 | 59882 | 56383 |
| XI | S-60 | 31186 | 21617 | 27917 | 30008 | 31186 | 30550 |
| XII | S-60 | 21823 | 18380 | 20563 | 21337 | 21823 | 21822 |
| *Total:* | | **993247** | 889932 | 969972 | **975804** | 958027 | 860411 |
| Loss against MAX: | | | 10,4% | 2,34% | 1,76% | 3,55% | 13,37% |

If we want to use the maximum monthly sums of the solar radiation we should change the setting of the receiver 7 times during the year. The adoption of a constant annual receiver orientation S-45 results in only 1.76 % of the losses of the total solar radiation as compared to the maximum values.

## THE SELECTION OF THE CONTROL PARAMETERS FOR THE TRACKING PHOTOVOLTAIC SYSTEMS

Optimistic claims of the manufacturers related to the apparent 40 % increase in the efficiency of tracking photovoltaic systems in comparison to the stationary ones have been verified experimentally in [9]. When designing this type of systems one needs to take into account the losses of the energy used for the control process and only then present the energy balance as a reliable one.

The energy losses are dependent on many factors: the frequency of adjustment of the plane angle of incidence of the photovoltaic system, the direction and strength of wind, ambient temperature etc. Most of these factors cannot be influenced but we can optimize the frequency of adjustments of the angle of incidence of the photovoltaic system towards the sun.

A proposal of a simplified method of optimization consists in a monthly averaging of the collected data (based on 30 years of observations) from the meteorological stations related to the solar radiation intensity for different combinations of the positions of the receiver as presented in figure 1. The next step is determining the maximum values of the solar radiation intensity for individual hours in each month. Based on such an analysis the results were obtained of the optimum positions of the plane of the solar radiation receiver plane as shown in table 3.

## CONCLUSIONS

1. The analysis of the data collected in the period of 30 years from the meteorological station located in Płock Trzepowo has shown that for the stationary photovoltaic system the optimum angle of incidence aiming south is $45^0$.

2. In the case of tracking photovoltaic systems, the analysis of the data from the meteorological station enables determining of a set of parameters for the control in two planes as shown in table 3.

3. In the winter months when the solar radiation is mostly diffuse, the changes in the setting of the plane of the photovoltaic system are not frequent: December-January a fixed position, February-November three positions.

4. In the summer months when the direct solar radiation component is prevalent, the optimum positioning

**Table 3.** Optimum orientation of the plane of the solar radiation receiver for the highest radiation intensity averaged to a representative day of each month in a calendar year

| Hours of the model day for a given month (hours UTC) | Month I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | |
| 6 | | | | | | E-60 | E-60 | | E-60 | | | |
| 7 | | | | | E-60 | | E-45 | E-60 | | | | |
| 8 | | | | SE-60 | | E-45 | SE-45 | | SE-60 | | SE-90 | |
| 9 | | SE-60 | SE-60 | | SE-45 | SE-30 | SE-30 | SE-45 | SE-45 | SE-60 | | |
| 10 | | | | | | | | SE-45 | | | | |
| 11 | | | | S-45 | S-30 | | S-30 | S-30 | S-45 | S-60 | S-60 | |
| 12 | | S-60 | S-60 | | | S-30 | SW-30 | | | | | |
| 13 | | | | | | | SW-45 | | SW-45 | | | |
| 14 | S-60 | SW-60 | SW-60 | | SW-45 | SW-45 | W-45 | SW-45 | SW-60 | S-60 | SW-60 | S-60 |
| 15 | | | | SW-60 | | | | | W-60 | | | |
| 16 | | | | | | | | | | | | |
| 17 | | | | | W-60 | W-60 | W-60 | W-60 | | | | |
| 18 | | | | | | | | | | | | |

of the photovoltaic plane requires several shifts in the position per day e.g. in July that is nine shifts.

5. The described method can be used for any given number of locations countrywide using the data from the closest meteorological station for the calculations.

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## METODA DOBORU OPTYMALNYCH PARAMETRÓW MONTAŻU DLA STACJONARNYCH I STEROWANIA DLA NADĄŻNYCH SYSTEMÓW FOTOWOLTAICZNYCH

Streszczenie. W pracy przedstawiono uproszczoną metodę doboru optymalnych parametrów montażu dla stacjonarnych i sterowania dla nadążnych systemów fotowoltaicznych. Metoda polega na analizie statystycznej dostępnych plików baz danych z pełnych 30-letnich obserwacji dla 43 stacji meteorologicznych na terenie Polski. Zastosowanie prezentowanej metody pokazano na przykładzie stacji meteorologicznej Płock Trzepowo. Na podstawie danych dla wybranej stacji opracowano zbiór optymalnych parametrów.

Słowa kluczowe: natężenie promieniowania słonecznego, kolektor słoneczny, konwersja fotowoltaiczna, panel fotowoltaiczny.