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OPTIMIZATION OF THE SOLAR COLLECTOR'S POSITION

Bogdan Sydorchuk[1], Oleksandr Naumchuk[1], Paweł A. Mazurek[2]
[1]Department of Automation and Computer-Integrated Technologies, National University of Water and Environmental Engineering, Rivne, Ukraine,
[2]Faculty of Electrical Engineering and Computer Science of the Lublin University of Technology, Lublin, Poland

Abstract: *It is made the mathematic model of determining of the solar collector's parameters, that allows to get its optimal values for any latitude at an any point of time. Also it is developed the computer model for determination of the daily influx of solar energy on the surface of the solar collector, which allows to determine its optimal position.*

Keywords: solar collector, optimal position, solar energy

OPTYMALIZACJA POŁOŻENIA KOLEKTORA SŁONECZNEGO

Streszczenie. *Skonstruowano model matematyczny określenia parametrów kolektora słonecznego, który pozwala uzyskać ich optymalne wartości dla dowolnego położenia geograficznego w dowolnej chwili czasowej. Opracowano model komputerowy, za pomocą którego wyznacza się dzienne dostarczanie energii słonecznej w stosunku do powierzchni kolektora słonecznego, co pozwala wyznaczyć jego optymalne położenie.*

Słowa kluczowe: kolektor słoneczny, położenie optymalne, energia słoneczna

Introduction

In recent decades, the practical use of solar energy, in particular by converting it into electrical or thermal energy is a particularly urgent issue. The direct conversion of sunlight energy into electricity is caused by photovoltaic generator – a device whose operation is based on the capacity of semiconductor solar cells under light exposure to generate electricity.

The flat solar collectors are the basic building block of solar power plant. Improvement of the effectiveness of the solar power plant can be achieved by improving structural features and by optimal orientation relative to the position of the Sun. To maximize the efficiency of solar collectors currently are used methods [7], supporting the solar module surface perpendicular to the sun's rays by means of:

- position sensors,
- GPS,
- computer programs with coordinates of the sun position for every day.

1. Statement of the problem and its relationship to important scientific and practical tasks

1.1. Analysis of recent research and publications which discuss current issues

The growing demand for innovative renewable energy sources leads to more meaningful study and research of solar power plants. Many scientific papers are devoted to the analysis and improvement of the solar collectors' design [8, 10] and to the methods for calculation of influx of the solar energy to the horizontal and vertical planes [2, 6]. A number of papers are devoted to finding the best angles of solar collector's position [4, 5] and the development of methods for improving the efficiency of solar power plants [1, 3, 7]. However, most research results is obtained for still or discrete-oriented installations [9, 11].

1.2. Formulation of the problem

The Sun in the sky is constantly moving. The position of the Sun in the sky depends on the latitude of the observer, as well as the time of day and season. To achieve maximum energy from a solar installation, you must follow the movement of the Sun and direct collector "to the Sun".

The object of this study is to determine the optimal position of the solar collector for any latitude at any point of time. In particular, determining the angle of inclination of the plane of the solar collector to the horizon α and to the azimuth of surface ψ_s (the angle between solar collectors' normal and the meridian) (Fig. 1) at which the total amount of solar energy S is directed to the maximum, namely $S = S(\alpha, \psi_s) \to max$.

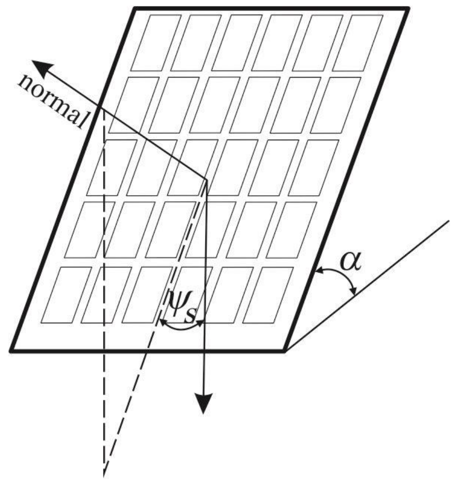

Fig. 1. The scheme of the solar collector's position

2. Statement of main research data with full justification of scientific results

The total amount of solar energy S that enters to surface *f* solar modules, that are randomly oriented in space, consists of direct and diffuse energy

$$S = S_n + S_p \,, \tag{1}$$

where S_n , S_p – the flows of accordingly direct and diffuse energy.

For the calculation of the direct solar energy flow is used the following equation [6]

$$S_n = S_m cos\theta \cdot K_{at} \,, \tag{2}$$

where S_m – the flow of direct solar energy near the earth's surface perpendicular to the beam surface; $\cos\theta$ – cosine of the angle of incidence of sunlight on this surface; K_{at} – coefficient, accounted for the alteration of the air mass, which ray has to pass through.

Value S_m and $\cos\theta$ are defined as [6, 10]

$$S_m = 1085{,}46 - 194{,}1\frac{1}{\sin h} + 11{,}36\frac{1}{\sin h^2} \,, \tag{3}$$

$$\begin{aligned} \cos\theta &= \cos\alpha \sin h + \\ &+ \sin\alpha\big((\cos\psi_s (tg \sin h - \sin\delta \sec)) + \sin\psi_s \cos\delta \sin\tau\big) \end{aligned} \tag{4}$$

where $\sin h = \sin \ \sin\delta + \cos \ \cos\delta\cos\tau$; φ – geographic latitude of the area; δ – declination of the Sun: $\delta = 23{,}5 \cdot sin(2\pi d / 365)$,

(d – the day of the year, $d = 1$ – is the 21st of March); τ – hour angle of the Sun in at the certain moment of time, which is measured from the moment of actual noon: $\tau = \pi(12-t)/12$; h – the angle that determines the height of the Sun above the horizon at the time t.

In accordance [2]:

$$K_{at} = 1{,}1254 - 0{,}1366\frac{1}{sinh}. \qquad (5)$$

With sufficient accuracy for randomly located surface of scattered solar energy S_p can be approximated by empirical relationship [2]:

$$S_p = 137{,}1 - 14{,}82\frac{1}{sinh}. \qquad (6)$$

So, considering (2)-(6), the equation (1) will be the following:

$$S = \left(1085{,}46 - 194{,}1\frac{1}{\sinh} + 11{,}36\frac{1}{\sinh^2}\right)\cdot\left(1{,}1254 - 0{,}1366\frac{1}{\sinh}\right)$$
$$(\cos\alpha\sinh + \sin\alpha(\cos\psi_s(tg\ \ \sinh - \sin\delta\sec\ \ ))) +$$
$$+\sin\psi_s\cos\delta\sin\tau + 137{,}1 - 14{,}82\frac{1}{\sinh}. \qquad (7)$$

Equation (7) expresses in general dependence of the influx of the solar energy on the randomly oriented surface, the position of which is set with the angles α i ψ_S for any geographic latitude φ at the certain period of the day (time angle τ) and at any day of the year (declination of the Sun δ).

On this basis, using the functions of Optimization Toolbox package of the Matlab program, we performed computer modeling the process of the influx of solar energy to the surface, the position of which is set by optimal parameters α *i* ψ_S for any φ, τ, δ in which $S \to max$. For the computer modeling by means of Script file it was created pop-up menu (Fig. 2), that allows in a visual mode data to calculate the optimal parameters ψ_S and α.

Also, by means of computer modeling it can be estimated the daily influx of solar energy to the surface, the position of which is characterized by respective optimal values α, ψ_S. For this aim the approximation of the functional dependence $S = S(\alpha, \psi_S, t)$ is conducted by the method of least squares.

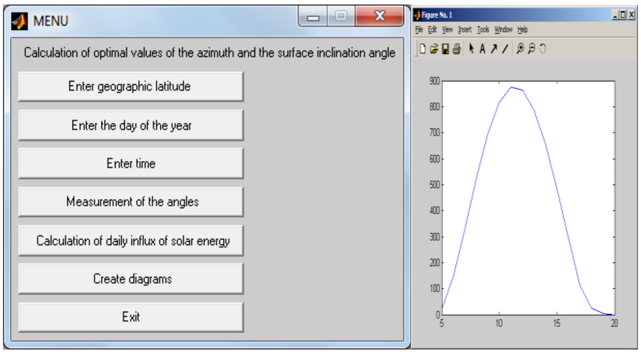

Fig. 2. The Pop-up menu for the calculation of the optimal values of azimuth and inclination angle of the surface

As it is shown at an example in Fig. 3 the comparative charts at $\varphi = 50°$, $d = 102$ (made by means of this program) the daily influx of the solar energy S: 1 – on a steady surface with constant angles $\alpha = 45°$, $\psi_S = 15°$; 2 – on the surface, the position of which is set with angles α, ψ_S where $S \to max$.

As we see a significant increase of the total solar energy, calculated according to the developed program, is obvious during the morning and evening hours. Because of this it's possible to take the direct flow of the solar energy which in the case of fixed solar power plants almost does not get on the surface of solar collectors.

On Fig. 4 we can see obtained by the program diagrams of the day shift $\alpha(t)$ i $\psi_S(t)$ for output data: the day of the year – 1st of July, geographic latitude $\varphi = 50°$.

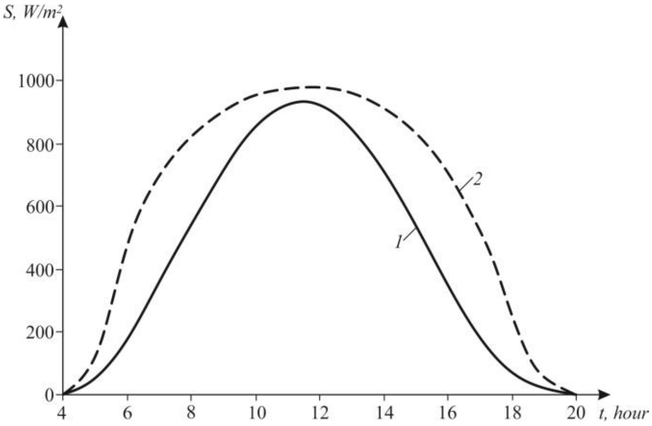

Fig. 3. The daily influx of the solar energy S: 1 – $\alpha = 45^O$, $\psi_S = 15^O$; 2 – $S \to max$

Similar estimates for $\alpha(t)$ and $\psi_S(t)$ and their respective diagrams are obtained for each day of the year and entered in a separate file.

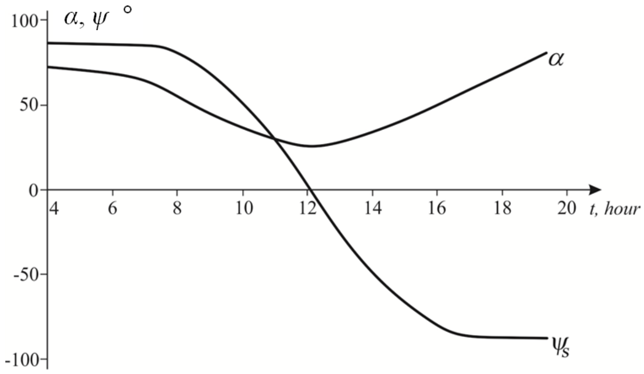

Fig. 4. The diagrams of the day shift $\alpha(t)$ i $\psi_S(t)$ where $S \to max$ ($\varphi = 50^0$, d=102)

Fig. 5 shows the phase portrait, where on each of the axes is indicated the value of the functions $\alpha(t)$ i $\psi_S(t)$, that allows to follow up the dependency of azimuth and inclination angle of the solar collectors during the day.

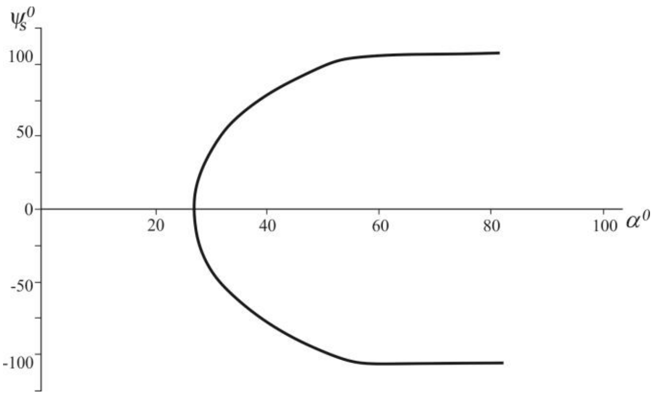

Fig. 5. The phase portrait $\alpha(t)$ i $\psi_S(t)$ ($\varphi = 50^0$, d=102)

Fig. 6 shows the diagrams of angles variation $\alpha(t)$ i $\psi_S(t)$ for all the months of the year.

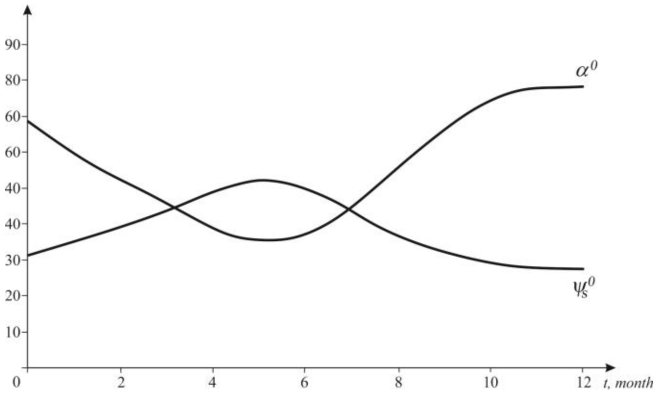

Fig. 6. The diagrams of variations $\alpha(t)$ i $\psi_S(t)$ where $S \rightarrow max$ during the year ($\varphi = 50^0$, t=10 hours)

As it was expected a significant variation of the optimal angles' values for the same time is obvious in autumn and winter, when the total solar energy flow is reduced.

3. Conclusions

It was developed the approach to the modeling and research of the parameters of the solar collector. Due to this approach it's possible to get its best values for any latitude at any point of time. Using developed computer model it is determined daily influx of solar energy to the surface, the position of which is characterized by respective optimal values α and ψ_S. It was confirmed that a significant increase of the total solar energy is obvious during the morning and evening hours, so the improvement of collectors' basic elements and efficiency of its functioning can be achieved by introducing structural changes to modules for increased efficiency, that would allow to take the flow of direct solar energy, which in the case of fixed solar power plant practically does not get to the surface of solar collectors.

The developed mathematical model allows calculate optimal azimuth for different latitudes as well as the angle of the plane of the solar collector to the horizon for each day of the year in which it's achieved a maximum influx of the solar energy. It was obtained estimated dependencies of the solar collector's on two angles (azimuth angle and inclination angle of the solar collectors' plane to the horizon) fall of the heat flow and its intensity, which confirmed the need for significant changes in these angles during the autumn-winter period because the overall income of solar energy is decreasing at this period.

Additional cases must take into account the practical installation of the positioner. Collectors have a permissible operating temperature, which cannot be exceeded. The system should have a positioner temperature sensor of absorber. If the temperature is too warm up the absorber, it is necessary to turn the system into the shade. It should be remembered also about protecting the collector against strong wind and snow. In case of strong wind protection collector is to set the collector to the horizontal position. In the event of snow protection collector is to set the collector in a vertical position.

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Ph.D. Bogdan P. Sydorchuk
e-mail: bogdan@terra.rv.ua

Associate professor of the Department of automation, electrical engineering and computer integrated technologies of the Institute of Automation, Cybernetics and Computer Engineering, National University of Water and Environmental Engineering, Rivne, Ukraine.
Engaged in identification and mathematical modeling of technological processes and facilities automation.

Ph.D. Oleksandr M. Naumchuk
e-mail: alexnu@ukr.net

Associate professor of the Department of automation, electrical engineering and computer integrated technologies of the Institute of Automation, Cybernetics and Computer Engineering, National University of Water and Environmental Engineering, Rivne, Ukraine.
Engaged in scientific research of effects of electromagnetic radiation from the mobile communication equipment on the environment, and mathematical modeling of technological processes.

Ph.D. Paweł A. Mazurek
e-mail: p.mazurek@pollub.pl

Assistant professor of the Faculty of Electrical Engineering and Computer Science of the Lublin University of Technology, Lublin, Poland.
Engaged in research on electromagnetic compatibility of electrical equipment, power quality, and the impact of electromagnetic fields on the environment.

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