ECONTECHMOD. AN INTERNATIONAL QUARTERLY JOURNAL – 2018, Vol. 07, No. 3, 33 – 38

Processing of data on the intensity of solar radiation for solar power plant management systems

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Received August 08.2018: accepted November 01.2018

Abstract. In the article is elaborated a method for estimating the amount of electricity that can be produced by solar panels for a short period of time (several hours). For estimating are used meteorological observations of different geographic points. This method of estimation can be used for optimization the internal structure of the hybrid power supply system.

Keywords: solar power plants, solar power, intensity of solar radiation, solar constant, coefficient of atmosphere's transparency.

INTRODUCTION

Due to lack of traditional energy resources and the environmental situation in the world, in many countries, and in Ukraine as well there is a tendency to increase the usage of renewable energy sources. One of the most commonly used alternative energy sources is solar energy.

The use of solar energy has several advantages such as: restoration, constancy, accessibility, environmental cleanliness, and others. However, it is not without disadvantages, the main of which is variability. Namely, the amount of electricity produced by the solar power plant is not a constant. It depends on many factors.

Therefore, in order to automate the management of solar power plants, it is necessary to be able to estimate the amount of electricity generated for a given geographic point. Because, the obtained values can be used to specify the setting of solar power control systems.

THE ANALYSIS OF RESEARCHES AND PUBLICATION

In recent years, many studies have been conducted on non-traditional energy sources. The theoretical foundations are described in such works [1-3]. It should also be noted practical work in the direction of forecasting and estimating the amount of electricity that can be produced by solar panels for the territory of Ukraine [4-8].

OBJECTIVES

The main objective of this paper is to develop a method for estimating the amount of electricity generated by solar panels for a given geographic point based on data from metrological observations.

MAIN RESULTS OF THE RESEARCH

Estimating the amount of energy that a solar panel (further SP) can produce over a period of time - a complex task, as the amount of energy depends on many factors. The last can be divided into solar panel technical specifications and environmental factors.

To the first group can be attributed volt-ampere characteristics of SP, idle voltage, short-circuit current and other factors. For simulating the process of converting solar energy into electricity are used several methods [9], namely: the method based on the efficiency coefficient (efficiency), the method of correction coefficients, the method based on the physical model, as well as statistical methods.

The second group includes the intensity of solar radiation coming on the unit of the solar panel surface, air temperature, humidity, and atmospheric pressure. Analyzing the results obtained in the work of Yurchenko A.V. [9], it can be argued that the main factor is the amount of solar radiation falling on the SP. The influence of other factors is extremely small, so it can be neglected.

The amount of energy that can be produced by the SP (E) is determined by the dependence:

$$E = \int_{t_1}^{t_2} f_{tr}(f_i(t))dt, \quad (1)$$

where f_i is the function that describes the dependence of the intensity of solar radiation falling on the unit of SP surface on time; f_{tr} is the function that describes the dependence of SP's power on the intensity of the solar radiation that enters its surface.

For simulation the process of transformation solar energy into electric is used the modeling method based on the efficiency. This method is used because it does not require a large amount of statistical data, in contrast to the statistical method, and does not require data from the volt-ampere characteristics of the SP, it means:

$$f_{tr}(I) = kI, \quad (2)$$

where, k is the coefficient that describes the efficiency of converting solar energy into electric energy by a solar panel.

The intensity of solar radiation (Isp), arriving on the unit surface of SP is determined by the correlation:

$$I_{сп} = \begin{cases} 0, \; if \; \alpha < 0, \beta < 0 \\ 0, \; if \; \beta_{sun} < 0 \\ I_{п} \cos\left(arctg\left(\sqrt{tg(\alpha)^2 + tg(\beta)^2}\right)\right), \\ if \; \alpha > 0, \beta > 0, \beta_{sun} > 0 \end{cases} \quad (3)$$

where direct SP-N - normal SP; A - the angle between the normal SP and the sun; $I_{п}$ – the intensity of solar radiation per unit perpendicular to the rays of the surface at the ground level; α – projection of the angle between the normal SP and the sun on the horizontal plane of SP; β – projection of the angle between the normal SP and the sun on the vertical plane of SP. β_{sun} – height of sun.

Using the methods described in [10,11] and in the works of other authors, one can determine the azimuth (α_{sun}) and the sun's height (β_{sun}) for a given geographic point. The intensity of solar radiation per unit perpendicular to the surface rays before entering the earth's atmosphere is called solar constant (S const) [12]. At an average distance between the Earth and the Sun this value is 1353 W/m^2, however depending on the month of the year, the value of solar constant varies from 1321 W/m^2 in early July to 1412 W/m^2 in early January. Thus, the annual variation in solar stability is 6.9%.

However, the main problem in assessing the intensity of solar radiation, which enters the unit surface of SP, lies in the fact that the atmosphere of the planet is not completely transparent. Transparency of the Earth's atmosphere depends on the season, the degree of cloud cover, humidity and other factors. For example, in conditions of a cloudless sky, only 80% of solar radiation reaches the surface of the Earth, if cloudiness is 5, then this figure is equal to 65%, and at 10 points - about 20% [13].

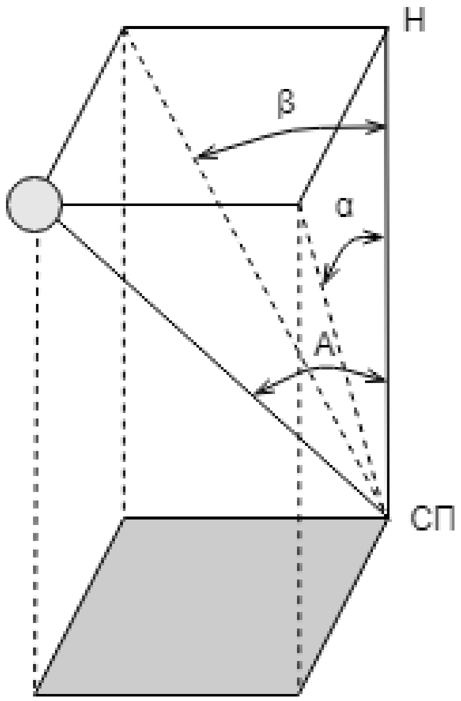

Fig. 1 Projection of angles to the plane

The coefficient, which shows the part of radiation that falls on the earth's surface due to the steep rays drop, it is called the transparency coefficient of the atmosphere (P) [5]. For the case of finding the sun in the zenith, this indicator can be calculated using the correlation:

$$\boldsymbol{P} = \frac{\boldsymbol{I_{в}}}{\boldsymbol{S_{const}}}, \quad (4)$$

where S_{const} is solar constant; $I_{в}$ is intensity obtained as a result of measurements.

In the general case, the transparency of the atmosphere can be calculated using the correlation:

$$\boldsymbol{P} = \sqrt[m]{\frac{\boldsymbol{I_{в}}}{\boldsymbol{S_{const}}}}, \quad (5)$$

where m – the optical mass, namely, the correlation of the path, that ray passes through the atmosphere to the shortest path that ray passes, when the sun is in the zenith [14].

The relationship between the height of the sun above the horizon and the optical mass is shown in Table. 1.

Table 1. Optical mass of the atmosphere

h, °	m	h, °	m
90	1	20	2.9
80	1.02	10	5.6
70	1.06	5	10.4
60	1.15	3	15.36
50	1.3	1	52.96
40	1.55	0	35.4
30	2		

Due to the fact that the coefficient of transparency of the atmosphere is influenced by many deterministic factors, therefore its forecasting is extremely difficult task. That is why, for the estimation of the intensity of solar radiation is used the average value of the transparency factor of the atmosphere P_s, which is characteristic for a given geographical point and month.

Summing up, it can be said that the amount of energy that can be made by the SP for the time from t_1 to t_2 can be determined by the following correlation:

$$E = \int_{t_1}^{t_2} k P_s^m S_{const} \cos\left(arctg\left(f_{\alpha\beta}(t)\right)\right) dt, \quad (6)$$

$$f_{\alpha\beta}(t) = \sqrt{tg\left(f_\alpha(t)\right)^2 + tg\left(f_\beta(t)\right)^2}, \quad (7)$$

where $f_\alpha(t)$ is the function that describes the relationship between time and horizontal projection of the angle between the normal of the sun and SP; $f_\beta(t)$ is the function that describes the relationship between time and vertical projection of the angle between the normal of the sun and SP. Thus, the only component that makes uncertainty in the process of estimating the amount of energy is the coefficient of transparency of the atmosphere.

In order to determine the coefficient of transparency of the atmosphere for the territory of Ukraine, the data on the intensity of solar radiation were processed from the site wunderground.com [15]. For the analysis 4 have been selected metro stations, which are typical for certain regions of Ukraine. Detailed information about the meteorological station is in Table 2.

Table 2. Data on the weather station

Id	Latitude	Longitude	Location
IKHMELNY12	50.088′N	26.795′E	Vaskivtsi, Khmelnytsky province
IGMINAPR3	49.794′N	22.720′E	Island, Poland
IKIEVKHL2	50.186′N	30.170′E	Mala Soltanivka, Kyiv province
I1149	46.561′N	30.839′E	Fontanka, Odessa province

In connection with the incompleteness of the data, it is necessary to conduct additional processing. An example is depicted in Fig. 2. The algorithm for additional processing of data consists in the following steps:

1. Reject all the values of intensity received during the night period. These values are in the range 0 - 1 W/m2.
2. Using the algorithms for calculating the position of the sun [10,11] we find the value of the intensity of solar radiation without taking into account the energy dissipation in the atmosphere (I_p).

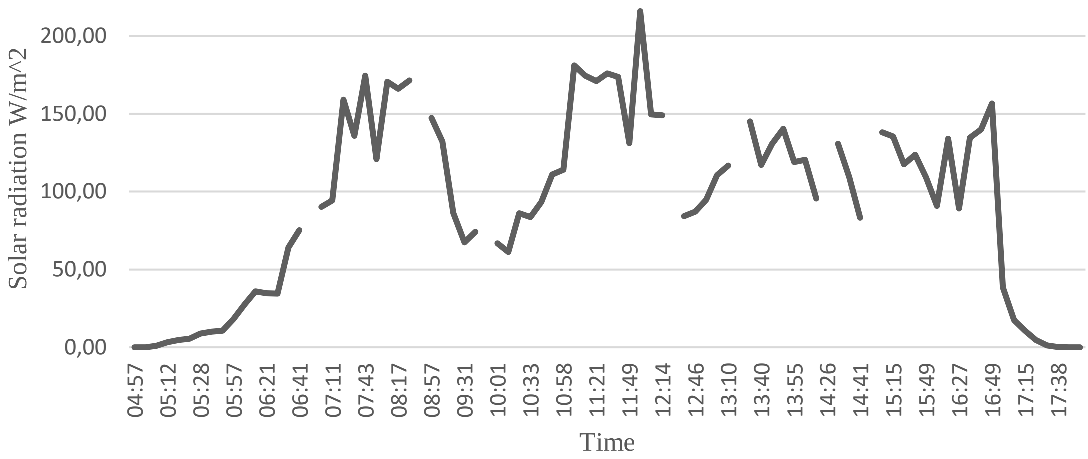

Fig. 2. An example of available data on the intensity of solar radiation [16]

3. Using the algorithms for calculating the position of the sun [10,11] we find the value of the intensity of solar radiation without taking into account the energy dissipation in the atmosphere (I_p).
4. Find the correlation of the intensity ($I_в$), obtained as a result of measurements, and the calculated intensity (I_p).

$$\boldsymbol{P} = \sqrt[m]{\frac{I_в}{I_p}}, \qquad (8)$$

where, m is optical mass.

5. We remove all the values of the atmospheric transparency coefficient, which are less than 0.05. The coefficient of transparency of the atmosphere varies within 0,8 - 0,2 [13].
6. Sort the received values by size with the set step is Δd.
7. We find the function of the probability distribution of the atmospheric transparency coefficient *f(p)* by dividing the number of measurements that are in the range of the total number of measurements. In fig. 3 shows an example of the distribution function found for the meteorological station located on the territory of the Kyiv region (id = IKIEVKHL2) [17].

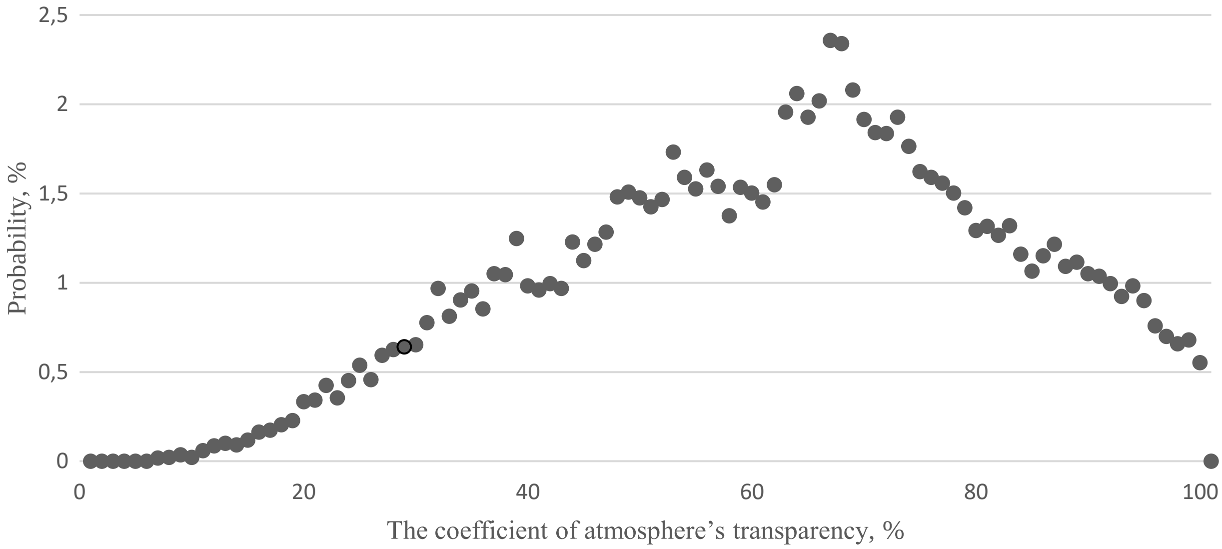

Fig. 3. Histogram of the probability distribution of the atmospheric transparency factor

8. We construct the probability distribution function of the atmospheric transparency factor F (P) based on the probability distribution function found using the relation:

$$\boldsymbol{F_x(x)} = \int_{-\infty}^{x} \boldsymbol{f_x(t)dt}\,. \quad (9)$$

9. Based on the obtained data, we find a mathematical expectation using the definition of Chebyshev and variance [18]:

$$\mu = \boldsymbol{E(X)} = \sum_x \boldsymbol{xp(x)}\,, \quad (10)$$

where, x is value of random variable; $p(x)$ is probability of occurrence of the corresponding value, with what:

$$\sum_x \boldsymbol{p(x)} = \mathbf{1}\,. \quad (11)$$

Using the method described above, were analyzed the data of meteorological observations, for 2017.01.01 - 2017.12.01, for given meteorological stations. Is determined the average value of the atmospheric transparency coefficient for the four geographic points. The results of the processing are shown in Fig. 4.

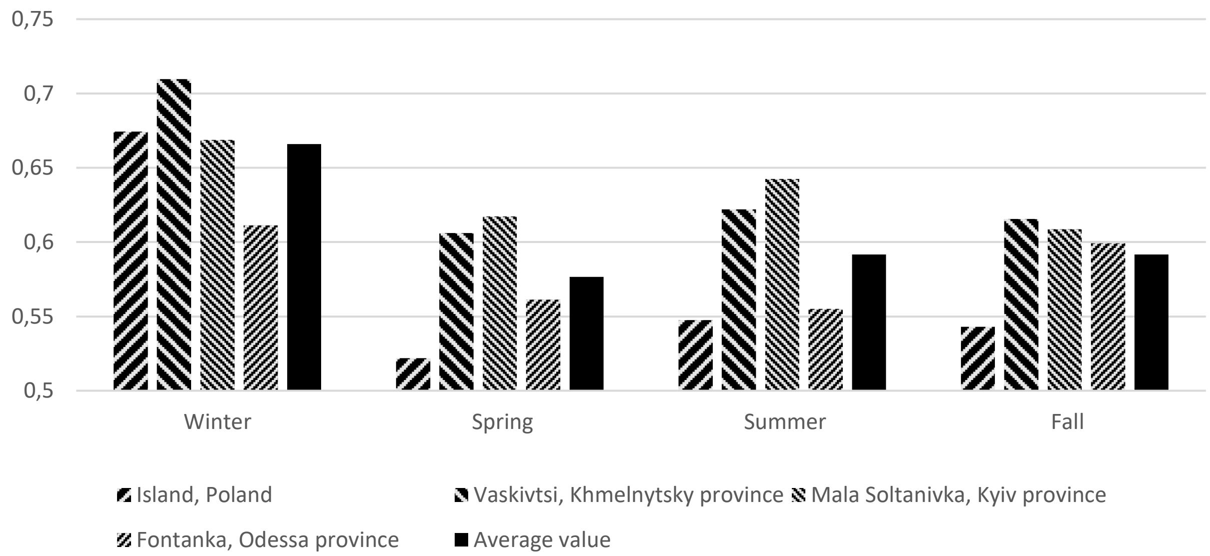

Fig. 4. The average value of the coefficient of transparency of the atmosphere.

The analysis of the diagrams (Figure 5) makes it possible to state that for the territory of Ukraine, the average value of the coefficient of transparency of the atmosphere for the winter period varies within [0.61; 0,7], for the spring period in the range from [0,52; 0.61], for summer [0.55; 0,64], and for the autumn [0,54; 0.61].

Let's estimate the amount of electricity that can be produced by one square meter of heat engineering SP located in the outskirts of Lviv during July 15. The SP is directed to the south at an angle of 35 °. Assume that the efficiency of these panels is 15%. In fig. 5 shows the results of the evaluation using the described algorithm. The graph shows the amount of electricity that can be generated by an SP within an hour.

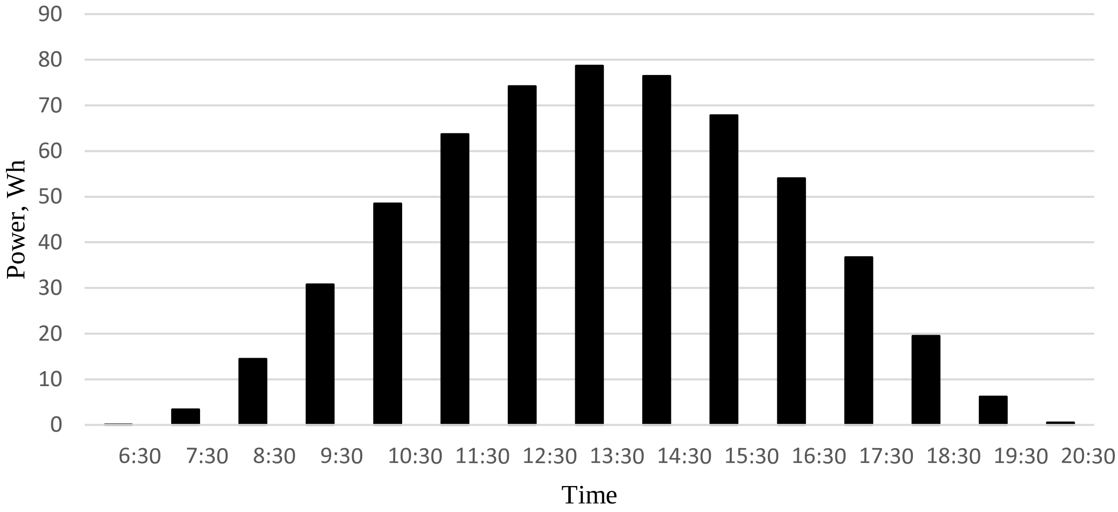

Fig. 5. Estimation of the produced amount of electricity.

CONCLUSIONS

The analysis of the obtained results, using the method of determination of the coefficient of transparency of the atmosphere, which is developed in the article, and the real data of the meteorological stations provides an opportunity to state:

1. For the territory of Ukraine, the values of the coefficient of transparency of the atmosphere lays in bounds: for the winter period [0.61; 0,7]; the spring period varies from [0,52; 0.61]; for the summer [0,55; 0.64]; for the autumn [0,54; 0.61];
2. The probability distribution of the atmosphere transparency coefficient is adequately described by the normal distribution law of the random variable;

The obtained results give an opportunity to specify the settings of the control systems of energy dynamical processes of hybrid power supply systems, and can also be used in the designing of such systems.

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