Determining the factors affecting the characteristics of photovoltaic modules in the conditions of Krasnoyarsk Krai

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Abstract. The paper determines the factors affecting the characteristics of photovoltaic modules in the conditions of Krasnoyarsk Krai. During the work the dependences of the energy of solar radiation in the territory of the Krasnoyarsk Krai on the height of the sun above the horizon, as well as the spectral composition of solar radiation on the same parameters were identified. The results obtained will help determine the rational modes of a photovoltaic power station and the need to use light filters in certain areas of the region.

Krasnoyarsk State Agrarian University is conducting research to improve the technical characteristics of photovoltaic power stations, studying the areas of their effective application in agriculture, as well as substantiating the areas of application in terms of economic efficiency.

A number of studies [1–5, 8, 13, 14, 17–19] revealed that the increase in energy generated by a photovoltaic power station on a cloudy and sunny day depends largely on a number of factors, one of which is the spectral composition of solar radiation irradiating the photovoltaic (PV) module.

According to the studies described by N.N. Kalitin in the book “The Rays of the Sun” [15], the intensity and spectral composition of radiation depend on the temperature of the heated radiating body. The spectral composition of radiation is related to temperature by the following regularity: the higher the body temperature is, the shorter the waves are which it emits and the greater the radiation intensity is. There is a definite relationship between the spectral distribution of the energy radiated by a blackbody and its temperature [15].

The intensity of radiation incident on a horizontal surface also depends on its angle of incidence and is described by the following dependence: if the sun rays fall at an angle of 30°, then radiation per unit area will be half as much as when they normally fall; at solar altitude angle of 10° it amounts six times less, and at a height of 5° - twelve times [15].

A sun ray traversing the Earth’s atmosphere, depending on the height of the sun above the horizon, passes through a greater or lesser mass of the atmosphere associated with the path length of the ray.

Solar radiant energy, passing through the Earth’s atmosphere, changes both quantitatively and qualitatively. This is due to a not completely transparent atmosphere. Some of the solar radiant energy is scattered along the way, some is absorbed [6, 7, 15].

Figure 1 shows the spectral composition of solar radiation for the visible part of the spectrum from the altitude 90° to 0.5°.
Figure 1. The spectral composition of solar radiation at different solar altitude angles: 1– red; 2– yellow; 3– green; 4– blue; 5– violet [15].

At a solar altitude angle of 90°, all five components, which together give white color, are in almost the same amount. As the sun approaches the horizon, the short-wave part weakens more than the long-wave part. With a solar altitude angle of 10°, half of all radiation is red rays, a quarter yellow and the last quarter three other colors. With the position of the sun at the horizon, there are practically no violet and blue rays, only red, yellow, and green remain, with the overwhelming majority being red [15].

To determine the height of the sun above the horizon, the time of day was calculated when the sun was at its highest point relative to the city of Krasnoyarsk as a reference point for further calculations of the solar altitude in the regional centers of the Krasnoyarsk Krai.

The calculations were conducted using the calculator for calculating the azimuth and altitude of the sun [16], with the presented calculation algorithm. In the calculator, select the city of interest (Krasnoyarsk), then select the day and month (for calculating the average monthly time, the 1st, 10th, 20th and 30th of the month were taken), next select the time at which the sun is at its maximum height (at the zenith).

The next step is to calculate the average monthly time of day the sun is at its zenith.

Table 1. Calculation of the average monthly time of day when the sun is at the zenith relative to the city of Krasnoyarsk.

| Month/time | Day of the month/time | Average monthly time |
|------------|-----------------------|----------------------|
|            | 1  | 10  | 20  | 30  |                  |
| January    | 12.58 | 13.01 | 13.00 | 12.56 | 12.57 |
| February   | 13.00 | 13.05 | 13.07 | 13.03 | 13.05 |
| March      | 13.02 | 13.00 | 12.58 | 12.55 | 12.59 |
| April      | 12.54 | 12.51 | 12.49 | 12.47 | 12.50 |
| May        | 12.47 | 12.46 | 12.46 | 12.47 | 12.47 |
| June       | 12.47 | 12.49 | 12.51 | 12.53 | 12.50 |
| July       | 12.53 | 12.55 | 12.56 | 12.56 | 12.55 |
| August     | 12.56 | 12.55 | 12.53 | 12.51 | 12.54 |
| September  | 12.50 | 12.47 | 12.44 | 12.40 | 12.45 |
| October    | 12.40 | 12.37 | 12.35 | 12.33 | 12.36 |
| November   | 12.33 | 12.33 | 12.35 | 12.38 | 12.35 |
| December   | 12.38 | 12.42 | 12.46 | 12.51 | 12.45 |

Knowing the average monthly time of the day the sun was at the reference point (the city of Krasnoyarsk), the solar altitude in the regional centers of the Krasnoyarsk Krai will be calculated using the same methodology as the calculation of the time of day.
As in the case of the calculator for calculating the sunrise and sunset times, the calculator allows one to set the coordinates and time zone manually. In the calculations, a negative height above the horizon can be obtained, which corresponds to the dark time of the day - the sun is “below” the horizon (in the northern regions of the Krasnoyarsk Krai).

Paul Schlyter, the developer of the calculator (Stockholm, Sweden), claims that the error in the calculations does not exceed one arc minute for dates in the range 1900 - 2100 [16].

For clarity and further data processing, the method of constructing models of curves and surfaces is applied using interpolation in the Matlab Application, CurveFittingToolbox [8 - 14].

After processing the vectors of data on the solar altitude in the regional centers of the Krasnoyarsk Krai for months, a graphic image is obtained.

In order to obtain data on the dependences of the distribution of solar energy on the solar altitude angle in the territory of the Krasnoyarsk Krai in selected coordinates (regardless of regional centers), a graphic image must be converted to three-dimensional surfaces, which will provide an opportunity to analyze and evaluate the dependences of the distribution of solar energy on the solar altitude in coordinates independently of regional centers (reference vector points) (figure 2).

![Figure 2](image_url)

Figure 2. The ratio of the solar altitude in the Krasnoyarsk Krai in January; annual average: ordinate axis - longitude, abscissa axis – latitude.

Obtained data on the solar altitude in the territory of the Krasnoyarsk Krai and the percentage of the spectral composition of solar radiation, depending on the height of the sun above the horizon, determine the dependence of the spectrum on the altitude in the territory of the Krasnoyarsk Krai.
Calculation of the results and processing of the data are conducted using the same method by constructing models of curves and surfaces using interpolation in the Matlab Application, CurveFittingToolbox (figure 3).

**Figure 3.** The percentage of the spectral composition of solar radiation on solar altitude in the territory of the Krasnoyarsk Krai.

The next step after determining the percentage of the spectral composition of solar radiation in the territory of the Krasnoyarsk Krai is determining the dependence of the radiation spectra on the solar altitude.

**Figure 4.** The spectral composition of solar radiation depending on the solar altitude in the territory of the Krasnoyarsk Krai.

Krasnoyarsk State Agrarian University conducts research to determine the rational modes of the photovoltaic power stations and identify factors that affect the output characteristics of the PV modules. Several studies have demonstrated that the increase in the energy generated by a photovoltaic power station on a cloudy and sunny day largely depends on the spectral composition of the light irradiating...
the PV module. During the work the dependences of the energy of solar radiation in the territory of the Krasnoyarsk Krai on the height of the sun above the horizon, as well as the spectral composition of solar radiation on the same parameters were identified. The results obtained will help determine the rational modes of a photovoltaic power station and the need to use light filters in certain areas of the region.

References
[1] Debrin A S and Ursegov V N 2016 Trends in the development of renewable energy electricity generation devices Proc. IX Int. Conf. on Innovative Trends in the Development of Russian Science (Krasnoyarsk: KSAU) 137-39
[2] Akhmetshin A T 2015 Improving the Efficiency of Autonomous Solar Photovoltaic Installations for Power Supply to Agricultural Consumers (Ufa) p 150
[3] Dubov V A and Chebadaev A V 2015 Evaluation of the effectiveness of the use of PV power stations for autonomous power supply of peasant farms Vestnik IrGSCHA pp 89-94
[4] Chebdaev A V, Bastron A V, Ursegov V N, Debrin A S and Smelova S A 2016 The use of photovoltaic power stations for autonomous power supply of peasant farms Proc. XIV Int. Online Conf. On Energy and Resource Saving (Oryol) pp 204-10
[5] Bastron A V and Gaydash G V 2015 The efficient use of solar energy in heat and power supply systems of rural manor houses and private household plots Vestnik IrGSCHA 67 92–100
[6] Timchenko S L, Dementyeva O Yu and Zadorozhny N A 2015 The influence of the radiation spectrum on the characteristic curves of the solar battery Physical Education of Students 21(1) 3-13
[7] Shatkovskis E, Mitkyavichyus R, Zagadskiy V and Stupakova I 2013 An abnormal increase in the fill factor of the current – voltage characteristic in the short-wavelength region of the solar spectrum for a silicon photocell containing a structure of porous silicone Technical Physics Letters 39(2) 23-29
[8] Debrin A S, Bastron A V, Semenov A F and Pashkevich T P 2019 Processing the results of studying the characteristics of photovoltaic power station and determining the rational operating modes when changing the angle of inclination and the spectral composition of the irradiation of PV modules Bull. of the Orenburg State Agrarian University 6(80) 175-79
[9] Debrin A S, Semenov A F, Bastron A V and Sebin A V 2019 Sertificate of state registration for computers 2019618249 on the program for determining the dependence of current strength on irradiation and the angle of inclination of the photovoltaic module (Krasnoyarsk: KSAU) No. 2019616917
[10] Debrin A S, Semenov A F, Bastron A V and Sebin A V 2019 Sertificate of state registration for computers 2019618248 on the program for determining the dependence of voltage on irradiation and the angle of inclination of the photovoltaic module (Krasnoyarsk: KSAU) No. 2019616911
[11] Debrin A S, Semenov A F, Bastron A V and Sutugina K A 2019 Sertificate of state registration for computers 2019610980 on the graphoanalytical processing of the results of a full-scale experiment to determine the dependence of the current-voltage characteristics of the photovoltaic module on irradiation and its angle of inclination (Krasnoyarsk: KSAU) No. 2019610005
[12] Debrin A S, Semenov A F, Bastron A V and Sutugina K A 2019 Sertificate of state registration for computers 2019610369 on the graphoanalytical processing of the results of a full-scale experiment to determine the dependence of the generated power on irradiation and the angle of inclination of the photovoltaic module (Krasnoyarsk: KSAU) No. 2018665181
[13] Debrin A S and Semenov A F 2019 Developing of a program for processing experimental data for determining the power and current-voltage characteristics of photovoltaic power stations Proc. Int. Conf. on Science and Education: Experience, Problems, Prospects pp 96-100
[14] Debrin A S, Semenov A F, Ursegov V N 2017 Modeling curves and surfaces of areas describing the results of field tests of photovoltaic power stations in the curve fitting toolbox Proc. X Int.
Conf. Dedicated to the Year of Ecology and the 65th Anniversary of the KSAU (Krasnoyarsk: KSAU) pp 104-107

[15] Kalitin N N 1947 The Lights of the Sun (Moscow: Acad. Sci. USSR) p 111
[16] Debrin A S, Semenov A F, Bastron A V, Zapletina A V and Chebodaev A V 2019 The study of the characteristics of photovoltaic power stations and the identification of rational operating modes by changing the inclination and the spectral composition of the irradiation Conf. Series: Earth and Environmental Science 315 032013
[17] Ozerova M G, Bastron A V, Debrin A S, Mikheeva N B and Ermakova I N The use of light filters in the photovoltaic solar power station to improve economic efficiency IOP Conference Series: Earth and Environmental Science 421
[18] Sheryazov S K, Chigak A S and Taimanov S T 2019 Research of energy characteristics of solar batteries Int. Conf. on Industrial Engineering, Applications and Manufacturing 8743093