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MAXIMUM ILLUMINATION CONTROL SYSTEM FOR PHOTOVOLTAIC PANELS ORIENTATION

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The article describes the solar tracker for photovoltaic panels and energy systems based on such devices. The authors introduce the results of calculations of the solar tracker application effectiveness for solar energy systems and the results of the field testing in Tomsk.

Key words:
Photovoltaic panel, solar tracking, single-axis tracker, two-axis tracker.

Introduction

Among the renewable energy solar radiation on the scale of resources, environmental friendliness and the general prevalence is the most promising.

This is topical to use solar power stations in regions without electrical mains. Replacing diesel generators on solar station in these regions not only helps alleviate the energy and environmental problems, it is also economically advantageous.

The main factor limiting the widespread use of solar energy in practice, is the cost of energy systems based on it. [1]

Incoming power calculation

On the basis of the twelve-year analysis of the photovoltaic module operation in Siberia was calculated the incoming solar radiation and designed a model with using single-axis and two-axis tracking system.

One of the factors that effect on the efficiency of photovoltaic modules is the angle of the sunlight incidence on their surface. Application of tracking systems will allow changing the inclination angle of PV depending on the sun position, which would be able to increase incoming power on its surface.

For the convenience of calculation, we assume that the Sun rotates around a stationary Earth.

The calculation of the tracking systems effectiveness was carried out. For this was defined the amount of incoming solar radiation per day. [2]

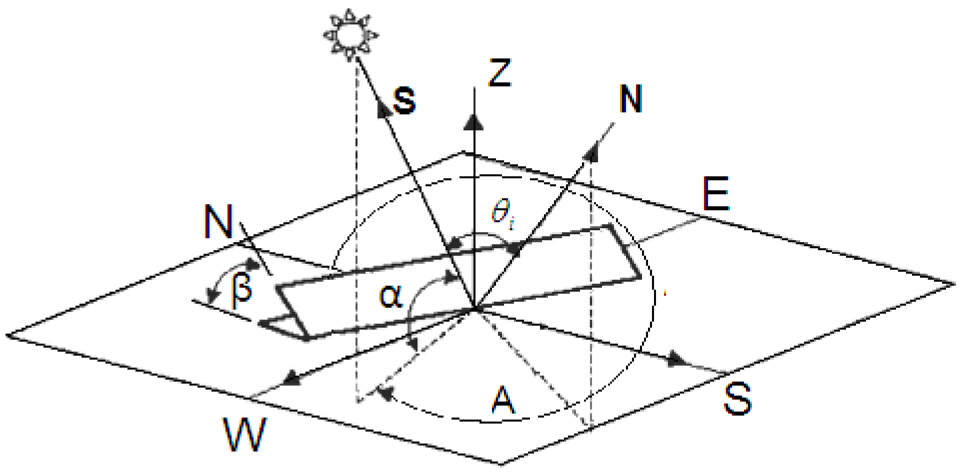

Fig.1. The Sun movement across the sky

When solar radiation passes through the atmosphere it loses its intensity due to absorption by ozone, carbon dioxide and water vapor, as well as scattering by particles.

Scattering and absorption increases with the increasing path of the sun's rays, so it is needed to use a correction coefficient for the approximation [4]:

$$K_{AT} = 1{,}1254 - \frac{0{,}1366}{\sin\alpha}, \tag{1}$$

where α - sun's height

Let us define the basic solar angles and their relation to the various ways of tracking for the sun.

— ω – an hour angle, measured in degrees. An hour angle increases to 15 degrees every hour and is equal to zero at solar noon

$$\omega = 15(t_S - 12)$$

where t_S – sun's time in hours.

— δ – Declination equals to the angular distance on the celestial sphere from the plane of the celestial equator to the light and is expressed in degrees of arc. Declination positive north of the celestial equator and negative to the south.

$$\sin\delta = 0.39795\cos[0.98563(N - 173)],$$

where N – a day number.

— α – sun's height, defined as the angle between the incident rays from the sun and the horizontal plane.

$$\alpha = \sin^{-1}(\sin\delta \cdot \sin\phi + \cos\delta \cdot \cos\omega \cdot \cos\phi)$$

— A – Sun's azimuth. This is the angle measured in a clockwise direction in the horizontal plane from the north.

$$A' = \sin^{-1}\left(\frac{-\cos\delta\sin\omega}{\cos\alpha}\right)$$

$$if\ \cos\omega \ge \left(\frac{\tan\delta}{\tan\phi}\right), that \cdot A = 180° - A'$$

$$if\ \cos\omega < \left(\frac{\tan\delta}{\tan\phi}\right), that \cdot A = 360° + A'$$

To determine the amount of radiation falling on an arbitrarily oriented platform, we introduced the notion of tracking angle θi, which expresses the angle between the direction of the sun's rays and the normal to the platform.

Cosine of the angle between the incident solar rays and the normal is the scalar product of the two unit vectors:

$$\cos\theta\, i = \mathbf{S} * \mathbf{N}$$

Equation for the cosine of the angle of incidence at a fixed panel:

$$\cos\theta_i = \sin\alpha\cos\beta + \cos\alpha\sin\beta\cos(\gamma - A) \tag{2}$$

It is useful to rewrite (2) in terms of latitude, declination and hour angle

$$\begin{aligned}\cos\theta_i &= \cos\beta(\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega) - \cos\delta\sin\omega\sin\beta\sin\gamma + \\ &+ \sin\beta\cos\gamma(\sin\delta\cos\phi - \cos\delta\cos\omega\sin\phi)\end{aligned} \tag{3}$$

For the horizontal position, the angle β is zero and equation (3) becomes

$$\cos\theta_i = \sin\alpha \tag{4}$$

and the inclined plane on the south side, we have

$$\cos\theta_i = \sin\alpha\cos\beta - \cos\alpha\sin\beta\cos A \tag{5}$$

Some types of photovoltaic modules work with monitoring rotation around one axis only. Incident rays (S) and the normal (N) lie in one plane. In general, for tracking a single horizontal axis:

$$\cos\theta_i = \sqrt{1 - \cos^2\alpha \cdot \cos^2(A - \gamma)}$$

Special case of this equation is often encountered in practice when tracking axes are oriented in the east-west direction, this is the case is of interest for the calculation.

$$\cos\theta_i = \sqrt{1-\cos^2\alpha\cdot\cos^2 A} \qquad (6)$$

With two axes tracking, a photovoltaic module will always be normal to the sun. Therefore, the cosine effect doesn't work

$$\cos\theta_i = 1 \qquad (7)$$

The incoming power can be calculated by the formula [3]

$$I_h = Am\cdot I_0\cdot\cos\theta_i, \qquad (8)$$

where I_0 – solar constant equals 1367 W/m^2.

Substituting alternate formula (2), (3), (6), (7) in equation (8), we obtain the values of the incoming power for photovoltaic module located horizontally and at an angle to the horizon, with the use of tracking systems.

The calculation results

On the basis of the calculating algorithm was build graphs depicting the tracking systems effectiveness for Tomsk and other cities of Russia. [2] The calculations have shown that a single-axis solar tracking system allows to increase the photovoltaic panels efficiency by 30%, and a two-axis solar tracking system increases it by 40%. Although, the second axis in the solar tracking system increases power generation by approximately 9% relative to the single-axis system, this considerably complicates the system design and increases its cost. So it is cheaper to use a single-axis solar tracking system and set the inclination angle relative to the horizon once in 2-3 months by hand because the sweep of the Sun above the horizon changes slightly during a year in contrast to the ecliptic, which changes during a day.

To assess the solar panels effectiveness was design a model with using different solar systems in Tomsk. The results are shown on the Fig.2. In addition, we calculated the effectiveness of solar tracking systems in other cities at different latitudes.

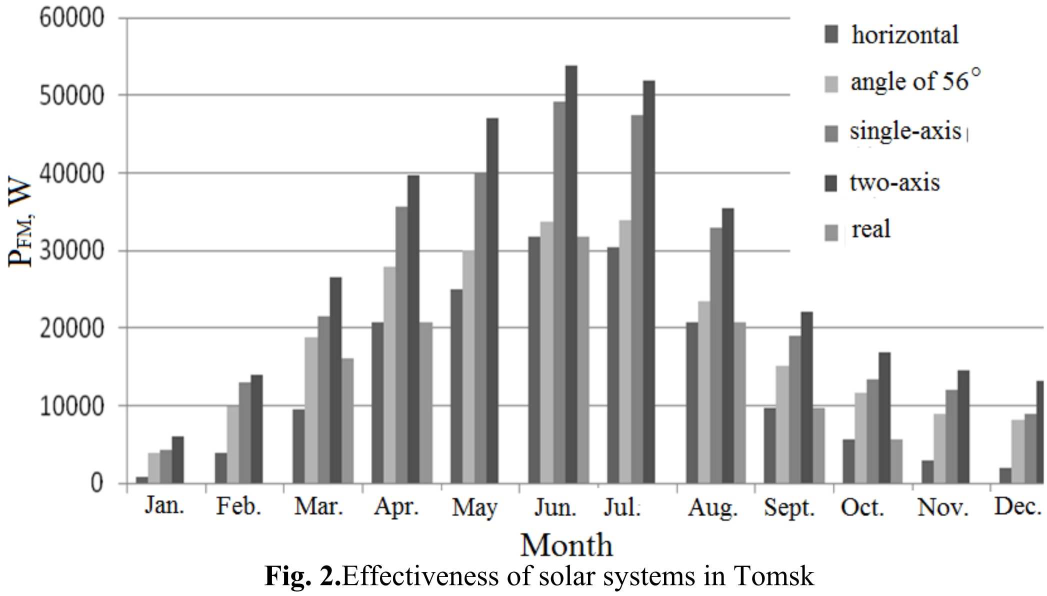

Fig. 2. Effectiveness of solar systems in Tomsk

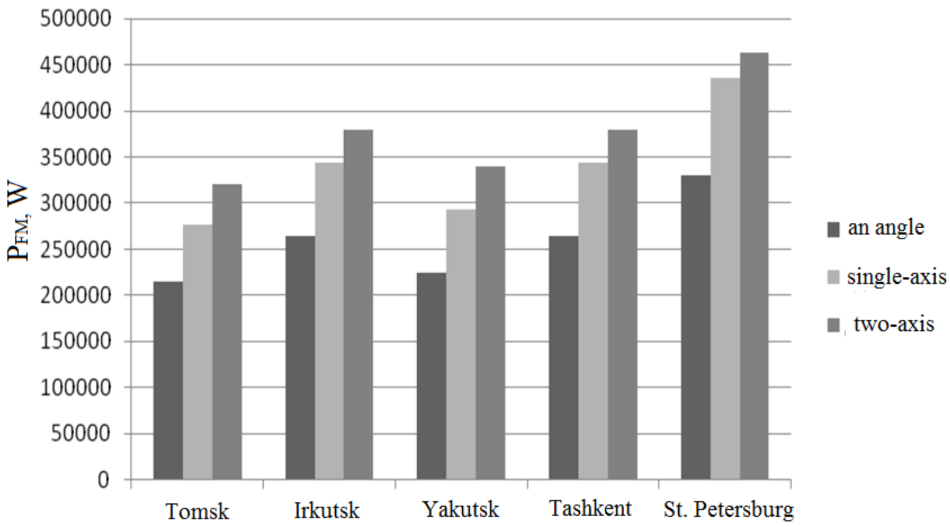

Fig. 3. Effectiveness of solar tracking systems in other cities

The photovoltaic sensor

For the tracking system was developed a photovoltaic sensor (Fig.4**)**. The sensor design makes possible to eliminate the effect of background radiation and solves the problem of the system start-up in the morning. The mathematical calculations of the sensor design was carried out and conducted its field testing in Tomsk. The results allowed to optimize the sensor and increase its sensitivity.

Elements A and B are installed on different sides of the partition, which allows to compensate the temperature difference influence. Also the partition is a conductive element. Element C is required for the measurement of the scattered radiation, its exclusion influence the other two sensor systems and run in the morning. The short circuit current of photovoltaic cells is used as the control signal, because it depends on the solar radiation intensity and doesn't depend on temperature.

To optimize the sensor design was carried out mathematical calculations and its field testing, using various angles between the elements A and B. The results of the field testing have shown that the maximum sensor sensitivity is achieved at the angle of 20 º. It can be seen in the directivity diagram and in the graph of sensor sensitivity dependence from the angle between the elements A and B (fig.5). As we can see the difference between the signals from the elements A and B is maximum at the chosen angle [3].

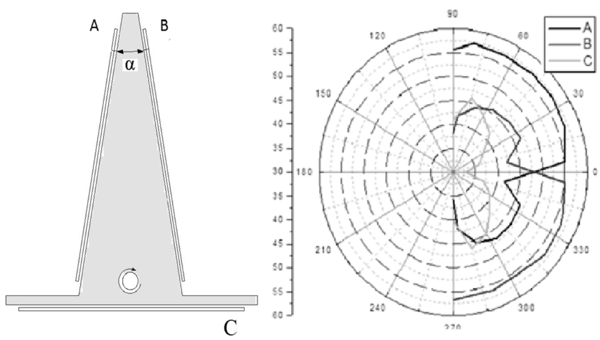

Fig. 4. The photovoltaic sensor and its directivity diagram

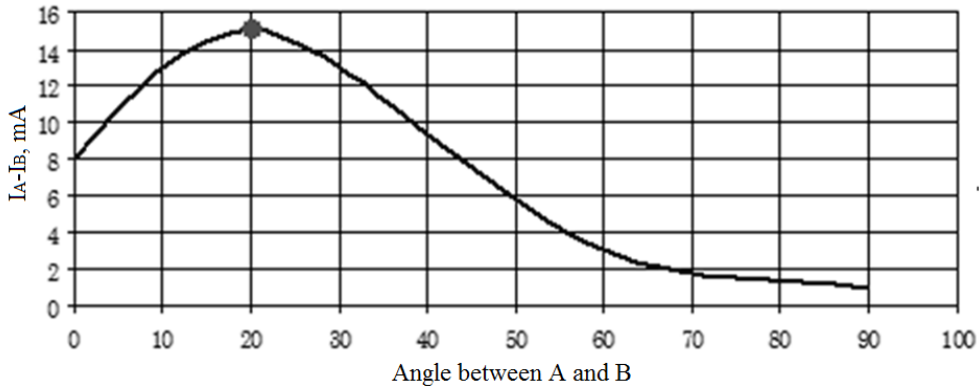

Fig. 5. The graph of sensor sensitivity dependence from the angle between the elements A and B

The solar tracking system based on the photovoltaic sensor

On the base of the photovoltaic sensor was developed the solar tracking system. The experimental model of 50 watt was designed and carried out its field testing.

The solar tracking system must consist of:

- A converter a solar radiation into current (the photovoltaic sensor);
- processing device of sensor signals and generating control signals for the engine (Microcontroller block);
- An motor, providing turn of photovoltaic module.

The block diagram of the solar tracking system consist of the photovoltaic sensor, the current to voltage converter, an operational amplifier, a microcontroller (MC), stepper controller (SC), and stepper motor [5].

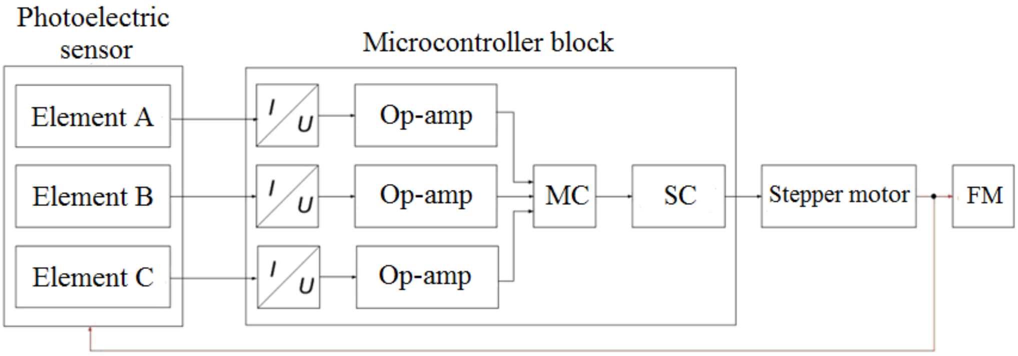

Fig. 6. The block diagram of the solar tracking system

On the base of the block diagram was developed a circuit diagram of the microcontroller block. On the design of the circuit diagram was developed the printed circuit board and designed the body for the microcontroller block. The algorithm of the microcontroller program was developed.

The efficiency of the solar tracking system was confirmed experimentally. The experimental model of the system was designed for a 5-watt photovoltaic module (fig. 7), then, carried out its field testing, using single-axis tracking system, two-axis system and without tracking system.

Fig. 7. The experimental model of the solar tracking system

The results of field testing was compared with the results of photovoltaic module installed permanently. The graphics of the comparison are shown in the fig. 9 and 10. The results of field testing shows that a single-axis solar tracking system increases the generated power of the photovoltaic module by 23% and a two-axis system increases it by 32% versus the photovoltaic module installed permanently.

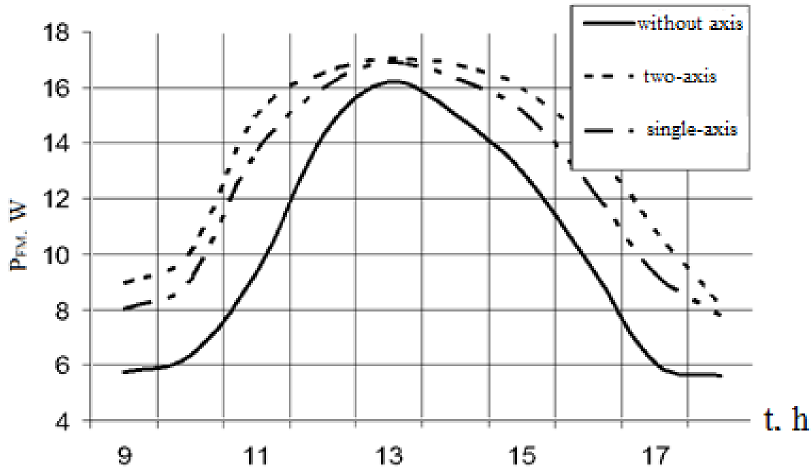

Fig. 9. Power per daygenerated by the systems

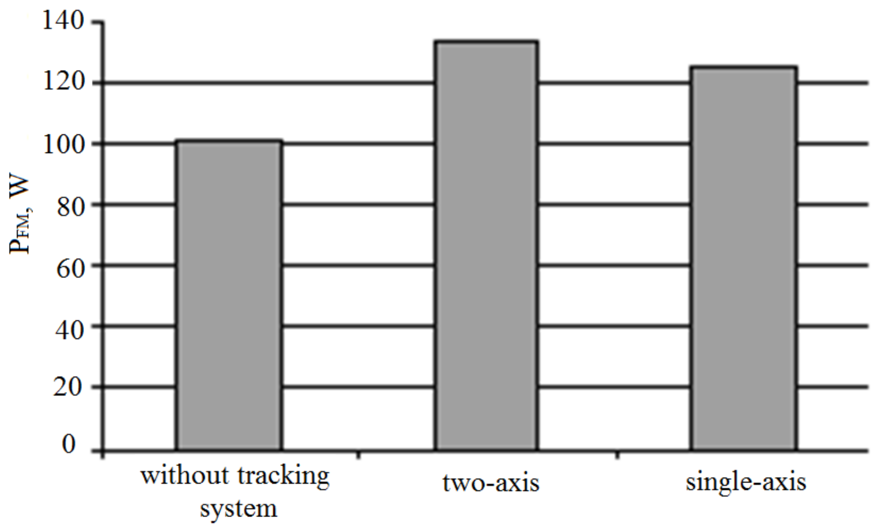

Fig. 10. Total power per day generated by the systems

The system step calculation.

The system step calculation is required for economical operation of the tracking system. From the analysis of the directivity diagram of the photovoltaic module [5], it is seen that within the 15 ° deviation from normal is no appreciable reduction of power generated. Thus, the discrete operation of the system will provide a reduction of energy consumption by moving parts tracking system.

Fix the photovoltaic module in one position for a long time and calculate the power generation change over time.

$$P_{ФМ} = КПД_{ФМ} \cdot I_0 \cdot K_{AT} \cdot \cos\theta_i \cdot \cos(\alpha_2 - \alpha_1)$$

The formula displays the amount of power generated from the time, where $\cos(\alpha_2 - \alpha_1)$ - the path traversed by the sun during the time interval.

Figure 8 shows that, without changing the direction of orientation, the system operates without a significant reduction in power: for a two-axis system for 1 hour, for a single-axis - an hour.

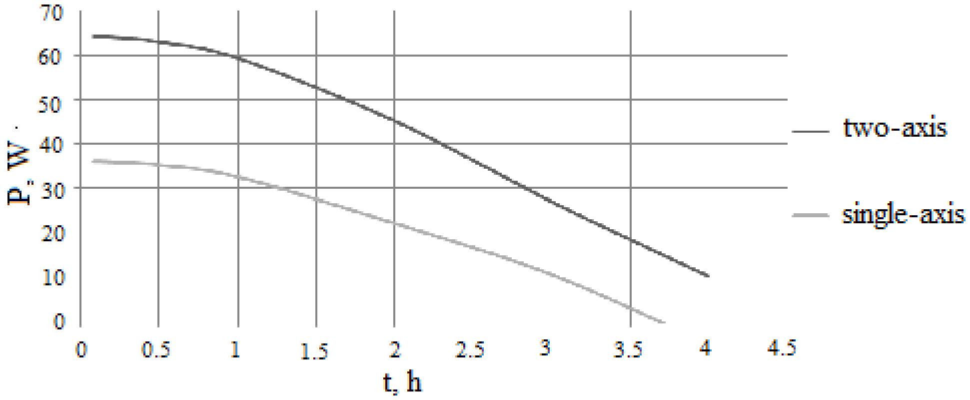

Рис. 8. Dynamics of generated power by photovoltaic module, when the tracking system is not oriented to the sun

Conclusions

5. A model of the solar tracking system was built and calculated its effectiveness in Tomsk.
6. A photovoltaic module was developed and carried out its optimization. Circuit diagram, the printed circuit board and an algorithm of the microcontroller program were developed as well.
7. The experimental model of the solar tracking system was developed carried out its field testing.
8. The optimization of the solar tracking system was carried out.

REFERENCES

1. Yurchenko A.V., Savrasov F.V., Yurchenko V.I. The real cost of energy - from resources to the consumer // Bulletin of the Tomsk Polytechnic University, 2009 - 314 tons, - № 3. - P. 43-46
2. W. Stine, M. Geyer. Power From The Sun// PowerFromTheSun.net URL: http://www.powerfromthesun.net/index.html (date of treatment 25.03.2014)
3. Kidruk M.I., Calculation of the solar radiation flux // progress21.com URL: http://progress21.com.ua/ru/articles/solarradiation (датаобращения 25.03.2014)
4. Ohorzina A.V., Kitaev M.V., Volgin A.V., Yurchenko A.V., Photoelectric sensor systems for tracking of the sun // Information and measuring equipment and technologies: Collected materials I Scientifically-practical conference dedicated to the 50th anniversary of the Department "Information and measuring equipment" of the National Research Tomsk Polytechnic University / ed. AV

Yurchenko; National Research Tomsk Polytechnic University. - Tomsk: Tomsk Polytechnic University in 2010. - p. 37-38
5. Ohorzina. A.V, Kitaeva M.V., Sumatokhina K.V., Optimization of photoelectric sensor for orientation system solar power systems // Modern equipment and technology: Proceedings of the XVII International scientific-practical conference of students and young scientists in 3 parts . - Tomsk: Publishing TPU. - 2011. - Volume 1 - p. 235-236

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