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CONTENT

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PHYSICS

Astronomical and geographical model for programming microcontrollers of ground-based trackers

V. P. Ivanytsky[1], M. M. Ryaboschuk[1], M. V. Stoika[2], S. V. Tiutiunnykov[1]

[1] Uzhhorod National University, 13, Kapitulna Str., t. Uzhhorod, 88000
[2] Ferenc Rakoczi II. Transcarpathian Hungarian Institute, 6, Kosuth square, Beregovo, 90200
[2]Corresponding author. E-mail: sztojka.miroszlav@kmf.org.ua

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Abstract. The prospects of using autonomous automatic solar orientation systems to increase the efficiency of small solar power stations are shown. A simple clear astronomical geographical model has been created to develop an algorithm for programming microcontrollers of autonomous trackers for an arbitrary point of the globe. The model is based on the geometric parameters of the Sun trajectory in the celestial sphere. The necessity of establishing the exact local solar time of the point of the power station location to achieve the maximum efficiency of its operation is shown.
Keywords: *resource-saving energy, ground-based trackers, solar orientation systems.*

Introduction. Nowadays, acceleration of the development of resource-saving energy and improving of energy efficiency are becoming global problems of all mankind. For their successful solution it is necessary to take into account a number of various interdependent factors: psychological, informational, environmental, organizational, political, economic, financial, technical, scientific, educational and others. In this regard, the development of solar energy seems to be the most prospective of all modern resource-saving energy areas. This is confirmed by the adoption of "The European Green Deal" [1] in 2020.

The main disadvantage of solar energy, like all other resource-saving technologies, is the higher cost of generated energy, compared to traditional sources. Therefore, nowadays "large" solar energetics is economically unattractive. Its development is stimulated mainly by global environmental and political motives, and the rapid growth of solar energy capacity becomes possible only with government support, including dotations in the form of a "green" rate. That's why it can be said that the development of resource-saving technologies in today energetics is funded by almost every citizen of individual countries and all mankind.

The efficiency of solar energy elements is determined by their physical and technical characteristics, external natural factors and technical conditions of their exploitation. To increase the efficiency of solar power stations and for adequate assessment of their energy generating capacity, it is necessary to take into account all three types of factors. In this case the transformation of solar energy into a highly profitable sector of the economics requires the use of all available opportunities to reduce the cost of solar energy. To do this, you can take advantage of the fact that solar energy is widely available everywhere. In our opinion, small solar energy with placement of solar elements on already ready designs of building of cities, villages and other geographical objects has wide opportunities in this respect. This approach is economically accepted by a number of positive conditions. 1. Land plots with high cost shall not be traditionally used. 2. Money is saved on structural elements of placement of solar cells. 3. Losses for energy transportation are significantly reduced, as the place of its generation practically coincides with the place of its use. 4. Energy consumption in the modern utilities sector is quite significant, the savings may also increase significantly due to the refusal from long electric transmission lines.

In addition to noted above, there is a number of technical possibilities to reduce the cost of solar energy, for example, by increasing the efficiency of energy elements. But this factor requires increased investment and additional research and design research of the new solar systems. This paper analyzes the possibilities of reducing the cost of solar energy using special technical systems of spatial orientation of solar cells, the so-called trackers. These systems set the optimal vertical and azimuthal angle of incidence of sunlight on the solar panel. This condition is provided by two main methods.

The first is the periodic seasonal manual reorientation of the panels according to changes in the maximum height of the Sun above the horizon. But the most likely locations for solar power generators for low energy are mostly fixed hard-to-reach structures (roofs, windows, translucent floors, etc.), for which, in most cases, manually changing the angular orientation of solar panels is difficult or impossible. Therefore, for small energy it is advisable to use the second method of optimal orientation using autonomous automatic systems. The maximum economic effect from operation of such systems is reached on condition of constant maintenance by them of optimum angles of orientation of solar elements. That's why the design of such systems requires the development of an accurate control algorithm for these systems. And this requires a detailed analysis of the relationship of technical parameters of such systems with the geographical features of their location and astronomical parameters of the Sun's motion in the celestial sphere.

The main control elements of modern electronic tracker systems are microcontrollers. Their use requires the creation of an appropriate mathematical model and control algorithm for all devices. According to these features, nowadays mainly two types of solar cell trackers are used: space and terrestrial. They differ in the optimal methods of tracking the spatial position of the Sun in the celestial sphere. For spacecraft, the use of photosensors for this purpose is optimal [2]. For terrestrial solar energy systems, the optimal method is to calculate the coordinates of the position of the Sun in the celestial sphere at the current time of solar time [3]. This work is devoted to the study of the issues noted above.

Literature review. For ground-based trackers it is necessary to have a mathematical model of operation of the control microcontroller. According to this model, an appropriate algorithm and control program for the entire tracking system is created. There are many studies devoted to this problem [4-6]. But most of them are characterized by common errors, inaccuracies, lack of verification of compliance with reality or too complex presentation of theoretical material.. As a result, for students and novice practitioners in the field of solar energy there are significant difficulties in mastering the theoretical basics of tracker systems. And to find out all the reasons why one or another mathematical relation borrowed from literary sources does not work is not justified to spend a lot of time.

Purpose. We will try to create our own simplest astronomical-mathematical model, which fully describes the process of orientation to the Sun and is suitable for use in microcontrollers trackers installed anywhere in the world.

Models and methods. Studies of the problems of orientation of solar elements are associated with the visible movement of the Sun in the celestial sphere. The last means a sphere of a certain radius, with the center O (Fig. 1), which is located at a given geographical point. A number of parameters important for the design of ground-based tracker systems are associated with the celestial sphere. The basic parameter of this sphere is its vertical, which passes through the center O (Fig. 1). A large circle of the celestial sphere that is perpendicular to the vertical and passes through the point O is called the mathematical (or true) horizon. A large circle of the celestial sphere, which passes through the vertical and through the Sun position point M is called the Sun height circle (Fig. 1). The axis of the universe is a coded line around which the visible rotation of luminaries on the celestial sphere conditionally takes place. The great circle of the celestial sphere, perpendicular to the axis of the world, is called the celestial equator.

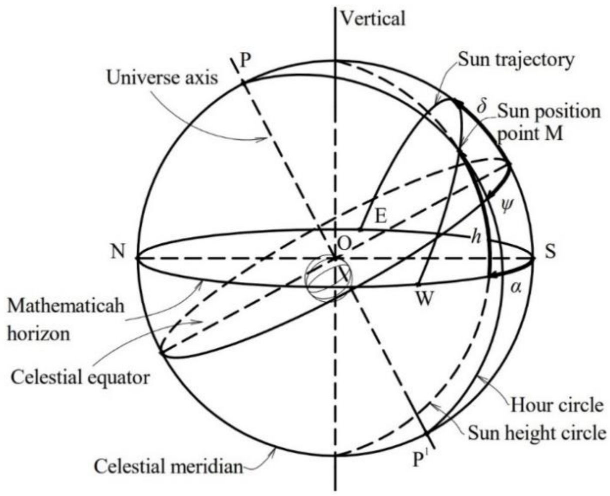

Figure 1 - The main celestial sphere parameters and Sun coordinates; N - the north point, S - the south point, P - the north world pole, P '- the south world pole

Setting the coordinates of the orientation of the trackers is associated with the consideration of the apparent motion of the Sun relative to the earth's surface in the celestial sphere. At the same time, the actual motion of the Sun in outer space is determined by its astronomical coordinates. To orient the solar elements, it is necessary to know the relationship between the geographical and astronomical coordinates of the position of the Sun at any time in the local solar time (local solar time LST) in a given area.

To determine the LST the concept of the celestial meridian of a large circle of the celestial sphere, which passes through the axis of the world and the vertical of the celestial sphere is used(Fig. 1). Thus for the beginning of reference LST the moment of passage by the Sun of a northern semicircle of a celestial meridian is taken. This event is called the lower culmination of the Sun or the true north and for it LST = 0. Accordingly, the true noon corresponds to 12 o'clock LST. This corresponds to the highest position of the Sun in the celestial sphere for a given day at a given point on the globe.

In clocks, time is set administratively through the time zones of the globe associated with their local standard time meridians (LSTM). This meridian is used to denote a specific time zone and to set the administrative solar time t for points on the earth's surface located on this meridian. Therefore, the administrative time we use in a given time zone is the LST value for the standard meridian of that time zone. It should be noted that for some countries the time t used may differ from the solar administrative time at certain time of the year when using daylight saving time transitions. Such events should be taken into account by the microcontroller program in the form of Δt_A correction, for the corresponding period of the year.

Results and discussion. Definition of LST. Within one time zone, the LST varies widely. Therefore, for a specific geographic location of a solar panel latitude D to determine LST, a correction (in minutes) $\Delta t_L = 4 \cdot (15° \cdot N_T - D)$ should be given during administrative time, where N_T is the time zone number of a specific area. It should be noted that the time zone numbers have a sign: for the western hemisphere the time zone numbers start from Greenwich ($N_T = 0$) and they are negative, and for the eastern hemisphere the time zone numbers also start from Greenwich, but they are already positive. In particular, the time zones of Europe correspond to the numbers $N_T = 0$, +1, +2, +3. Therefore, the correction Δt_L can be both positive and negative. In addition, it should be borne in mind that the value of D is set separately for the western and eastern hemispheres of the Earth in the range from 0 to 180 °.

The movement of the Sun in the celestial sphere is quite uneven due to two main phenomena: a) our planet moves in its elliptical orbit faster in the region of perihelion and slower in the region of aphelion; b) the plane of the ecliptic (the trajectory of the Sun's motion in the celestial sphere among the stars during the year) has a certain inclination to the plane of the celestial equator. Such effects are taken into account by the total correction to time t in the form of an empirical relation, which is called the equation of time [7] $\Delta t_E = 9{,}87 \cdot \sin(2B) - 7{,}53 \cdot \cos(B) - 1{,}5 \cdot \sin(B)$, where $B = 0.986 \cdot (N - 81)$, and N is the day number from the beginning of the year. In the given equation, the parameter B has the unit of measurement is radians, and the correction Δt_E is the unit of measurement of the minute. The Δt_E correction on each particular day of the year is the same for observers at any point on the Earth's surface.

Analysis of these relationships shows that for any time zone, the maximum value of the time correction Δt_E does not exceed 20 minutes, and the correction Δt_L 40 minutes. Then the maximum total time correction for solar orientation systems can be taken equal to 1 hour. This corresponds to the deviation of the direction of incidence of solar radiation from the normal of the panel at an angle of about 15º. This deviation will correspond to a reduction of the energy flux falling on the panel by about 5%. This deviation persists throughout the operation of the solar panels. Therefore, calculations show that for the European region, ignoring these corrections in tracker systems for different geographical installation points of one kilowatt solar panel will lead to total annual electricity losses in the range from 50 kWh to 100 kWh. In our opinion, the calculated losses for low-capacity power plants are significant. Therefore, the corrections Δt_E and Δt_L to the local solar time are very important when designing the systems of orientation of the elements to the Sun.

The main contribution to the time correction is made by the component Δt_L. In this case, it is defined once as a fixed constant only when mounting the system in a given area and does not change during operation of the installed solar power plant. The Δt_E correction is constantly changing from day to day. The nature of these changes is such that in the most active summer period of electricity generation, the majestic Δt_E does not exceed 8 minutes, and this correction reaches its maximum value in the autumn-winter period. As a result of introducing the Δt_E correction into the microcontroller program, it gives an average daily energy increase of about 2% of the design capacity.

Thus, in solar orientation systems, the value of the exact local solar time can be calculated by a simple relation: LST = t - ($\Delta t_L + \Delta t_E + \Delta t_A$). Accordingly, an independent clock should be entered in the electronic orientation device and set to the administrative time t in the corresponding time zone N_T. The data of this clock will be used by the microcontroller to determine the order of actions of the executing devices of the orientation system at each time of LST operation of the solar panel.

Time angle calculations. In the development of orientation systems, the values of LST are translated into degrees, entering the hour angle ψ, which is also called the solar angle. To determine it, use the concept of the hour circle (or the circle of inclination of the Sun) is a large circle of the celestial sphere, which passes through the axis of the world and through the Sun (Fig. 1). Then the time angle is called the angle ψ from the upper point of the celestial equator (south point) to the hour circle of the celestial sphere. The time angles are calculated in the direction of the apparent diurnal rotation of the celestial sphere.

According to the definitions of ψ and LST, there is a difference between them, which corresponds to 12 hours. Therefore, if the microcontroller of the orientation system is configured to determine the LST for the area, the time angle is easily calculated by the ratio $\psi = (\text{LST} \pm 720) / 4$. Here LST is set in minutes, and the time angle ψ is calculated in degrees. Thus before noon in a ratio it is necessary to take a sign "minus", and in the afternoon a sign "plus".

The Sun inclination, height and azimuth angles. By definition (Fig. 1), the Sun inclination is the angle δ between the celestial equator and the plane of the trajectory of the diurnal motion of the Sun on a particular day of the year (Fig. 1). The main astronomical coordinates of the Sun's position M are its height h and azimuth α (Fig. 1). The Sun height h is determined on the Sun height circle. It is the angle between the plane of the mathematical horizon and the point M. The Sun azimuth α is determined in the circle of the mathematical horizon as the angle between the south point S and the Sun height circle. The azimuths of the Sun are calculated in the direction of the visible diurnal rotation of the celestial sphere.

Conclusions. One of the ways to solve the problem of resource conservation is the most efficient use of material and technical facilities of those solar power plants that are being built. This is due to the fact that the production of such facilities requires significant cost of raw materials and energy. Therefore, their operation should give the maximum possible positive effect. In this regard, the use of autonomous automatic solar orientation systems to increase the efficiency of small solar power plants is quite promising. The cost of production of such systems does not exceed 15% of the cost of a solar power plant. The use of orientation systems in small solar power plants increases the efficiency of energy generation by 30-40%. We have created a simple mathematical model of the algorithm for programming microcontrollers of autonomous orientation systems, which provides maximum power from the installed small power plant. This model can be used for equipment installed at any point on Earth. The model is based on the principle of determining the exact local time with reference to the geometric parameters of the trajectory of the Sun in the celestial sphere.

REFERENCES

1. A Eurpopean Green Deal 2019, An official website of the European Union, accessed 23 March 2021, <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en>.
2. Navigation 2016, NASA Sceince, Solar System Exploration, accessed 23 March 2021, <https://solarsystem.nasa.gov/basics/chapter13-1>.
3. David Cooke, Single vs. Dual Axis Solar Tracking // Alternate Energy magazine, April 2011.
4. Alistair B. Sprou, 2007. Derivation of the solar geometric relationships using vector analysis // Renewable Energy, Elsevier, v. 32(7), p.1187-1205.
5. Lorenzo Mari, 2020. An Introduction to Solar Geometry for Solar Cell Optimization // EEPOWER, Technical article, accessed 23 March 2021, <https://eepower.com/technical-articles/an-introduction-to-solar-geometry-for-solar-cell-optimization/#>.
6. Karttunen H., Kröger P., Oja H., Poutanen M., Donner H. J., 2003. Fundamental Astronomy. 4th ed., Berlin: Springer.
7. Equation of time 2021, Wikipedia, the free encyclopedia, accessed 23 March 2021, <https://en.wikipedia.org/wiki/Equation_of_time>.

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