Journal of International Scientific Publications: Materials, Methods and Technologies

Volume 8, ISSN 1314-7269 (Online), Published at: http://www.scientific-publications.net

ENERGY-EFFICIENT PHOTOVOLTAIC INSTALLATION

Aleksandr S. Petrusev, Yermek Zh. Sarsikeyev, Danil Yu. Lyapunov

National Research Tomsk Polytechnic University, 30, Lenin Ave., Tomsk, Russia, 634050

Abstract

In this paper R&D basics for photovoltaic installation development are presented. Efficiency of energy conversion process depending on the azimuth and zenith angles of the installation's rotation is investigated. Recommendations on the installations' class design are given. Technical and economic assessments of the proposed solutions are made.

Key words: *solar tracker, solar cell, acrylic concentrator, efficiency, photovoltaic modules.*

Currently in Russia there is an acute problem of the lack of cheap electricity in the areas with decentralized electric power supply. Now that area is embracing about 70 % of the country with a population of 20 million people [1]. Currently stand-alone diesel systems use allowы to get only a very expensive electric power, which in some towns costs under 56 rubles per kW·h and above. It is therefore very important in such areas to use autonomous renewable energy sources, which include solar energy. Now solar power engineering development is progressing at a rapid speed – 30% per year. In 2013 the solar power plants of total power about 30 GW were put into operation, whereas the total power in 2012 was 102 GW. In addition, taking into account the purity and the prevalence of renewable energy sources, solar energy is one of the most promising. But at the present moment solar power plants have two weighty drawbacks, delaying their mass distribution. The drawbacks are the high price of solar cells and relatively low efficiency of conversion the solar energy into electric energy during the entire day.

The aim of this work is to search the appropriate methods of increasing the efficiency of solar energy conversion into electric energy and to develop the experimental sample of the installation.

The high price of solar power plants is determined primarily by high cost of photocells per kW of electric power. If the efficiency of photocells is increased using, for example, instead of single-crystal cell (efficiency 15-17%) gallium arsenide cells (efficiency 30-35%), the cost is increased many times (about 40 times) – from about 2,5$ to 100$ per kW, respectively. Therefore it is more promising not to increase the efficiency of photovoltaic cells, but to amplify the incident solar energy since the output power of photocell is almost directly proportional to the incident solar energy. There are 2 ways to do this: to orient the solar panel on the sun by using a solar tracker or to concentrate solar energy by using a solar concentrator.

Solar concentrator is a device that allows to collect solar energy from a larger area and direct it to a smaller area. Now solar concentrators are mainly represented by parabolic mirrors and Fresnel lenses. There are also other various mirror systems with different degree of concentration, but they are not widely used due to various weighty drawbacks. Parabolic mirrors are very large and heavy because of their design, which does not allow to make them smaller. Hence the system is subjected to an increased risk of breakage. The mirrors also require very precise orientation to the sun and powerful cooling systems, otherwise their efficiency is extremely reduced. Fresnel lenses have a smaller, but still substantial thickness, and also require more precise orientation and more powerful cooling. Moreover they are quite expensive.

In the present work a unique acrylic solar concentrator that solves the problems mentioned above is proposed. Fig. 1 schematically shows a cross section of the acrylic solar concentrator. It corresponds a plate of plexiglas's with thickness about 1 cm, consisting of a special reflective surface and two wedges. The inclined planes of the wedges are directed opposite to each other and have a gap between them filled with a special glue. The concentrator developed allows to collect solar energy by entire receiving surface and direct it into the end faces where the photocells are placed. This occurs due to calculated and exactly matched refractive indices in the concentrator's medium, as well as the angles of the wedges and the edges of reflective surface.

Volume 8, ISSN 1314-7269 (Online), Published at: http://www.scientific-publications.net

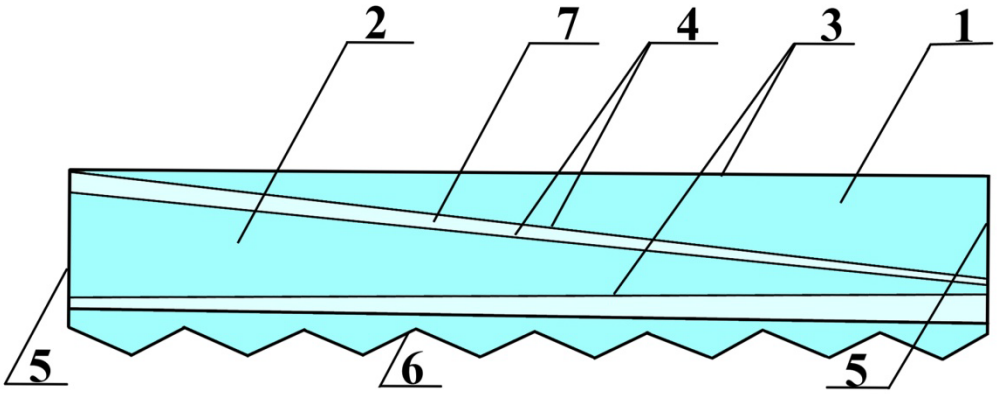


Fig. 1. Cross-section of acrylic solar concentrator

The principle of operation of the solar concentrator is based on the phenomenon of total internal reflection. Sunbeams, falling on the working surface 3 of the optical wedge 1, are partially reflected, and the rest, undergoing refraction at the interface penetrate inside the wedge. Depending on the refractive index of the wedges' material, optical medium 7 and the wedge angle, the sunbeams trapped in the wedge 1 either are reflected from its surface 4, or pass through it and optical medium 7 inside the wedge 2. The optical medium 7 has a refractive index smaller than the refractive indices of the optical wedges 1 and 2. Due to the effect of total internal reflection of the sunbeams reflected from the surface 4 of the wedge 1 fall ultimately on the base 5 of the optical wedge 1. The sunbeams which have passed through the optical wedge 2, penetrate through its operating surface 3 and fall on light deviating element 6, which reflects the sunbeams back into the optical wedges 1 and 2. Light deviating element 6 is performed so that the sunbeams reflected from it enter the wedges 1 and 2 at the angles providing their total internal reflection within the wedges with a further incidence of light on the end faces 5 of the wedges.

Since the relation between receiving surface area of one wedge end face of the solar concentrator is as 1 to 14, 7-fold concentration of solar energy with efficiency of 75% is achieved. The efficiency is calculated theoretically and confirmed experimentally. The concentrator has a small weight and size, large directional pattern on the sun and does not require powerful cooling systems, allowing to use only passive radiators.

The calculations of the efficiency of the solar concentrator subject to the angle between the concentrator surface normal and the line of sunbeams falling are carried out by ZEMAX software. It was found that it works effectively in the range from –3 to –0,1 degrees on one axis and from –30 to 30 degrees on the other. Therefore for the orientation only one plane is needed. However, under such conditions, a solar tracker which performs a movement of at least one axis is required.

Solar tracker is a device directing solar panel or solar concentrator to the sunbeams, allowing to produce more energy during the day. Trackers are divided into active, passive and manual. The most versatile are the active orientation systems, as they are able to operate automatically, as well as to find the most actively radiating light source, and not to rely on prepared movement program. The trackers can be oriented either by one axis or by 2 axes. Although the two-axis orientation gives a small gain compared to a single-axis one, it is quite complicated and more expensive [2]. Therefore, in terms of given geographical location, unique single-axis active solar tracker is proposed. Its principle of operation is based on the analog-digital signal of control board, which avoids the use of microcontrollers and stepper motors, allowing to reduce the system total costs and to simplify it, maintaining quality and reliability.

The formula of the dependence between the power that reaches the photocells and the angle of sunbeams incidence on the solar panel is derived. The tests which confirm the dependence obtained were carried out.

The solar battery was installed in the initial position perpendicular to the incidence of the sunbeams with a help of a tube in which there was a longitudinal through hole (the orientation took place before the occurrence of bright luminous point under the tube). Then, using the pyranometer installed the same way the amount of total solar radiation incident on 1 square meter perpendicular to the line of sunbeams incidence was measured.

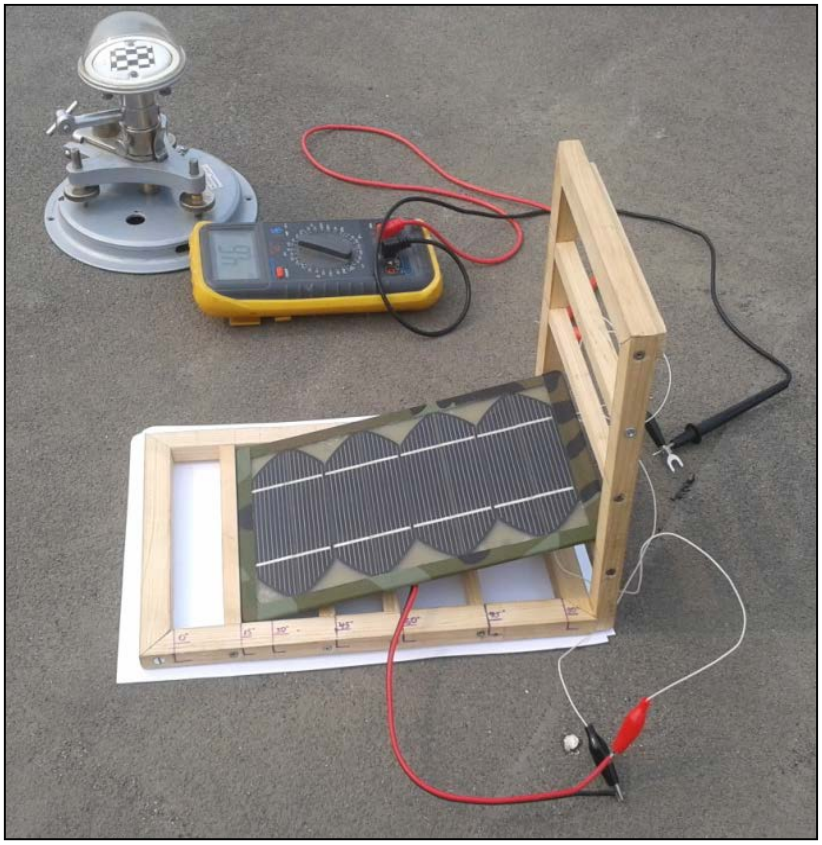


Fig. 2. Photovoltaic module investigated

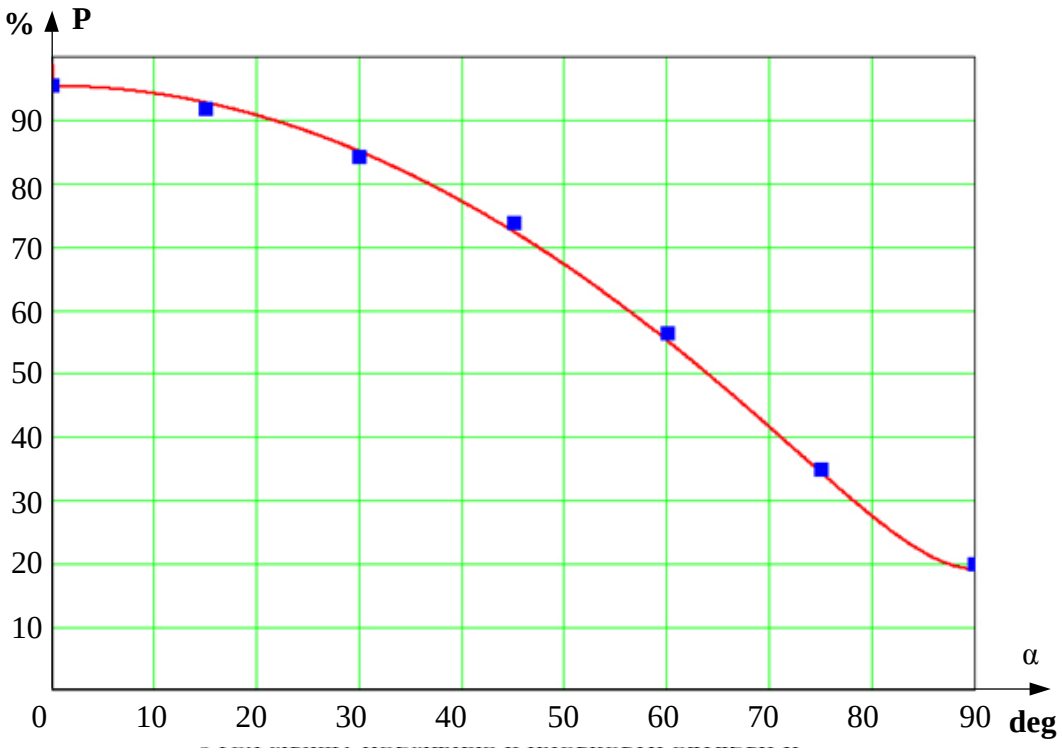


Fig. 3. Dependence of sun radiation incident power on the slope angle

After that the solar panel power was calculated by measuring its current and voltage at different angles of incidence between the normal to the photovoltaic module and the line of sunbeams incidence. The angle of incidence was regulated using a specially designed rack. The photovoltaic module fixed on the rack could take stable positions with increments of 15 degrees (Fig. 2). Three measurements for each angle were carried out. The arithmetic mean values of the measurements was recorded in the table and noted on the curve of the solar panel power-angle of incidence.

As a result, it was found that the points of the graph and the theoretical curve obtained are almost completely coincided. Slight variations are due to the fact that the measurements were not instantaneous, but within a ten minute period of time. The radiation power within the period can vary. The accuracy of the orientation to the sun and measuring instruments are also the factor of variations occurred (Fig. 3).

Further calculations showed that without tracker solar panel loses about 40% of electric power during the day [2].

The model of reduced scale, demonstrating the principle of operation of solar tracker, was designed and assembled (Fig. 4).

Main components are:

• Battery powering the motor and the external circuit (1);

• Control board that regulates the rotation of the installation (2);

• Motor performing rotation (3);

• Limit switches (4), which not allow the solar panel to rotate for more than 180 degrees, preventing wire break;

• Solar cell (5), fixed at an angle of 45 degrees to the horizontal, which charge the battery;

• Switch (6), which enables or disables the system;

• Output jacks (7), connected to external circuit, allowing to supply some electrical equipment.

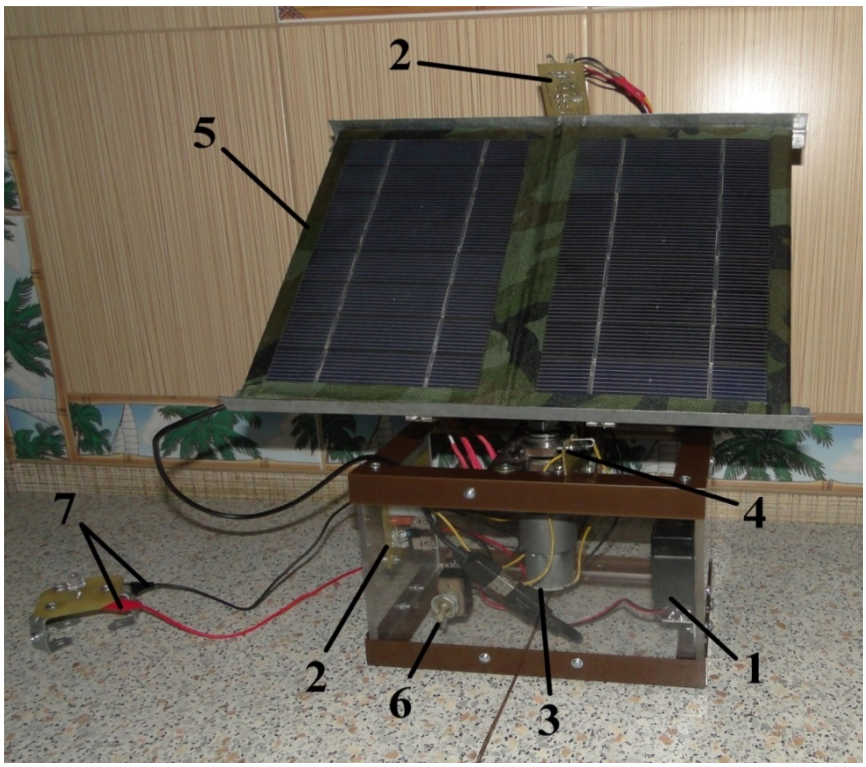


Fig. 4. Solar tracker design

Limit switches correspond two boards fixed near the shaft which rotates the solar panel. Their principle of operation is based on optocoupler principle. When the metal plate is placed between the light emitting diode (LED) and photodiode the output current stops to flow in the specified direction. This allows to turn off the tracker when it reaches a certain critical angle.

The main part of the installation is the control board. Its principle of operation is based on 2 LEDs, arranged at an angle of 40 degrees relative to each other. Sensors for the control board are LEDs and not photodiodes. Due to the fact that the principles of their operation are similar in many respects, the LEDs can be used instead of more expensive photodiodes.

When photons of light hit the LEDs' n-layer the electrons are knocked out. Most of them are recombined due to the fact that they cannot overcome the much wider p-n junction than that in photodiodes. Nevertheless, a small number of electrons still overcome it. The potential difference occurs and current begins to flow, which is amplified by means of transistor amplifier installed in the board.

When the solar radiation falls more on one of the diodes of the board, the control signal is generated. The signal enables the electric motor to rotate the entire installation.

Important feature of this board is the ability to adjust the step of tracking system. By changing the resistance of potentiometer used in the board it is possible to change the time between the solar tracker operations from a few seconds to several hours. This is essential due to the fact that the sun moves around relative to a solar panel slowly and continuously whereas switched on solar tracker consumes an excessive electric power. Therefore it is more efficient to put the solar tracker into operation for definite time intervals. The dependences of the system's power on the orientation step were calculated. They showed that the most efficient system must have the orientation step of 1 hour for solar panels and 8 minutes for solar concentrators.

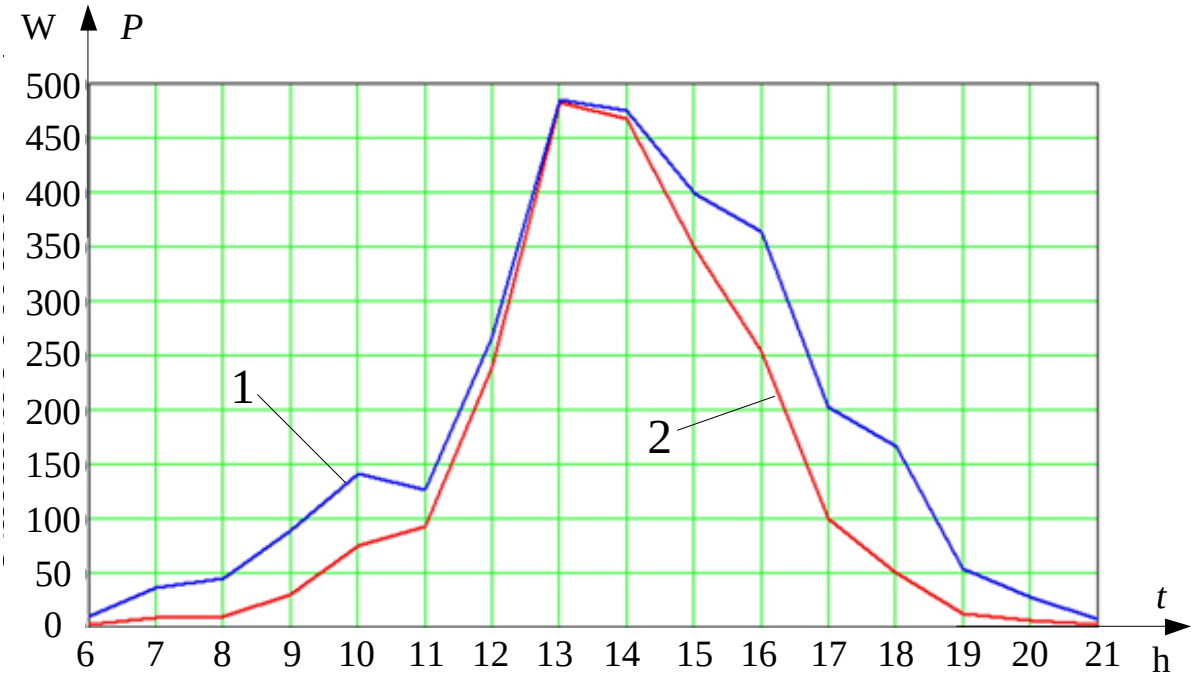


Fig. 5. Dependence of output electric power produced of orientable solar panel (1) and static solar panel (2)

The calculations of efficiency increase of solar panels with tracker were carried out. For example in Tomsk region during the most bright and warm days, the power of total solar radiation reaches a peak at 1100 W/m^2, and in the cold winter indicator drops to 150 W/m^2. The graph of the total solar radiation for August 14th, provided by the site of atmospheric composition climatology of Tomsk region was taken [4] (on the 14th of August, it was about the average value of solar radiation between summer and winter). The data on azimuth and zenith of the sun in the Tomsk region on August 14th were also provided.

The results of the calculations in the form of dependences of output power on time are represented in Fig. 5. The curve 1 corresponds to the solar panel with solar tracker, the curve 2 – without it. It may be concluded that when

the orientation system is used the output power is substantially higher than that for static solar panel, excluding the interval from 13 to 14 PM, when the sun is in the south.

According to the results obtained by calculations the use the solar tracker can increase the efficiency for 30-35% for solar cells and several times for the solar concentrators. Solar concentrator and tracker simultaneous application reduces the cost of solar power by more than a factor of 2 for monocrystallic solar cells and 4-5 times for gallium arsenide solar cells.

The laboratory installations of the solar concentrator (1 W) and solar tracker (10 W) were created. The work on scaling the samples, as well as on the possibility of replacing the acryl by polyester in solar concentrator is currently carried out.

CONCLUSION

On the example of Tomsk region it is proved that solar power plants use for autonomous electric power supply objects is efficient. Therefore, among the known ways the methods of azimuth orientation of solar panels during the day are considered and implemented. Furthermore, in order to increase efficiency it is proposed to use the acrylic solar concentrator. The result of the work is the photovoltaic installation, which contains the photovoltaic modules and the original control system.

REFERENCES

Feodor V. Savrasov, 2013, ‘Energy-efficient autonomous photovoltaic electric power supply systems’, PhD thesis, National Research Tomsk Polytechnic University, Tomsk.

Zekai Sen, 2008, Solar Energy Fundamentals and Modeling Techniques, Springer-Verlag London Limited, London.

Baden Powell, 1856, On the demonstration of Fresnel's formulas for reflected and refracted light; and their applications, Bodleian libraries, Oxford.

Laboratory of Atmospheric Composition Climatology, 2012, Solar Radiation Dependence on Time, viewed 14 August 2012, <http://lop.iao.ru/eng/index.php/about-tor-station/meteo>.