Exploring the effectiveness of using devices that follow the Sun

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Abstract. The article is devoted to the study of the effectiveness of devices that follow the Sun. For this purpose, the construction of a two-axes tracker with an automatic system of steering the solar panels on azimuth during the light period of the day and with the possibility of manually adjusting the angle of rotation of the solar panels on the zenith, depending on the season is designed. For the proposed construction, the calculation of the angles of the zenith is made and the optimal angles are selected for manual adjustment of the seasonal positions of the system. The photo modules, which are installed stationary on the developed tracker system, are selected. Structural and electrical principle diagram of the stand was developed for determining the efficiency of solar power station, equipment was selected and its manufacture made. A solar power station monitoring system has been developed, which enables to automatically visualize parameters, perform data processing in real time, create databases and perform a comparative analysis of their operational efficiency in an automatic mode. Experimental researches have been carried out on determination of the generated electric energy by static and dynamic solar power stations, on the basis of which the efficiency of tracker systems of rotation of solar panels is confirmed. The use of dynamic systems compared to static allows to increase the production of electricity by 33% under the same conditions. But with poor illumination of the panels (rain, fog, cloudy weather), the tracker's effectiveness decreases and it does not exaggerate 5% when fully covered with the sky. Therefore, the use of tracking systems in the absence of direct sunlight on the surface of photo modules is not feasible.

1 Introduction

Solar energy is one of the promising directions of renewable energy sources that have been actively implemented in recent years in the world industry and life [1, 2]. Solar energy systems and devices allow efficient production of electric and thermal energy, thanks to the natural, practically inexhaustible possibilities of light radiation of the Sun with the least impact on the environmental state [3].

There is a colossal amount of solar energy that comes on the surface of the planet Earth. At its power, the weekly solar radiation exceeds all the world's known reserves of uranium, oil and coal. One of the benefits of solar power is that it is environmentally friendly. In its production, carbon dioxide is not formed, as, for example, at thermal stations. Unlike atomic power plants, it is completely radiation-safe. When it is made, waste is not formed that requires further utilization (slag, radioactive waste). That is why at present solar power is one of the most actively developing. For example, the total power of all solar power stations in the world in 2010 was 40.3 GW, and in 2022, according to Solar Power Europe,

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it will be 621.7 GW, which is more than twice the power of all existing nuclear power plants.

Improving the technology of producing electricity from the energy of the sun leads to the fact that over time, solar energy will become the cheapest among other alternative sources of energy. That is why studies conducted in the field of solar energy are relevant.

2 Problem statement

The difficulty of using the solar energy with a photoelectric panel is created by seasonal and daily unevenness of solar energy. This unevenness of energy flow can be caused by the Sun, weather conditions, as well as the daily course of the Sun in the sky. Effective use of solar energy by a photoelectric panel depends on its orientation in space. This will ensure a minimum deviation of the angle of incidence of sunlight to the normal photovoltaic panel during the year and the light period of the day [4].

There are two main types of solar panel mounting systems: static and dynamic. The static system is characterized by the fact that the orientation of the modules and the angle of inclination with respect to the Sun are unchanged. It is logical that solar modules should be maximally illuminated during daylight hours, so they should be oriented toward the south. If for some reason there is no such opportunity, then the solar panels can be installed on the south-west or south-easterly direction. The performance of the solar panels is also influenced by the angle of inclination, which is set depending on the location of the location of the solar power station [3].

One of the most effective methods for increasing the electrical performance of photo modules is the use of dynamic mounting systems and the use of devices that track the Sun (trackers). The advantage of moving trackers is that the solar panels placed on them automatically move in the sun during the day and change the angle of inclination depending on the season, which can significantly increase the efficiency of the station and increase the production of electricity compared with fixedly fixed solar panels [3, 5].

The choice of a tracker type depends on many factors, including the size of the installation, electrical parameters, land restrictions, latitude and local weather conditions.

Among the most commonly used panel orientation systems, the following can be distinguished: continuously-tracking with the position sensors of the Sun and continuous or discrete-tracking with program control [4]. In addition, they can be made by one- or two-axis position at the axis of rotation [3].

Trackers with one axis of rotation – single-track trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of a single-axle tracker is usually oriented along the north-south axis. It is possible to orient them in any coordinate directions using tracking algorithms.

Trackers with two axes of rotation have two degrees of freedom, which act as axes of rotation. These axes, as a rule, are not connected with each other, but work together. The axis that is fixed in relation to the Earth can be considered as the main axis. Another axis can be considered as secondary. Such trackers usually have modules oriented parallel to the secondary axis of rotation. They allow taking the optimal amount of solar energy due to their ability to monitor the sun in both vertical and horizontal directions.

Summing up the advantages of dynamic systems for fixing photovoltaic modules, it is necessary to develop a tracking tracker system that would significantly improve the productivity of solar panels and explore its parameters.

3 Analysis of recent research and publications

In connection with the development of electric drives and power electronics, photomultipliers increasingly use dynamic automatic systems for directing photo modules on the Sun, which provide an increase in their productivity, from different sources, from 25 to 47% [6, 7]. The advantage of such guidance systems is that the solar cells placed on them automatically move around the Sun throughout the day and change the angle of inclination depending on the season. This significantly increases the power generation compared to stationary (immobile) fixed solar panels due to the fall of sunlight at an angle of 90° to the plane of the panel during the light day, leading to the generation of maximum energy, which in turn provides the maximum energy efficiency of solar panels.

Analysis of technical literature has shown that the greatest energy generation occurs when the tracker system turns the solar panels to a maximum angle in the azimuth plane. The zenith angle of the slope of photo modules, depending on the time of year, does not significantly affect the production of electric energy. Therefore, it can be set the same for all seasons as optimum for a certain area, or regulate manually. Using an additional actuator to move the solar panel azimuthally leads to an additional cost of electricity for its power supply.

4 Presenting main material

The design of the tracker system of solar panels (Fig. 1) is proposed, which consists of: a carrier design of the tracker; azimuth orientation system; actuator; photoelectric sensor and microcontroller to control the orientation process [3].

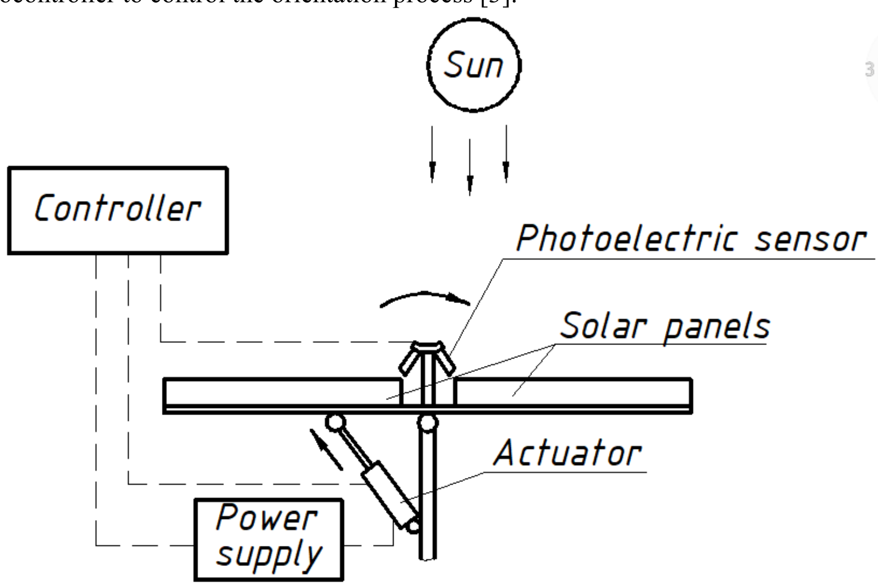

Fig. 1. Design scheme of the tracker system of solar panels.

A kinematic scheme of the tracker mechanism was developed (Fig. 2, 3) and the sizes of all the components included in it were calculated. A double-axes tracker for rotation of solar panels was designed on the basis of the obtained data.

The technical capabilities of the design of the tracker allow rotate the panels to the maximum angle in the azimuth plane. The zenith angle is manually adjusted by means of traction. To do this, a calibration is applied on the frame, which allows the seasonal positions to be displayed by the labels. This made it possible to significantly reduce the cost and simplify the design, which in turn reduced the payback period of the plant without significant losses in the efficiency factor.

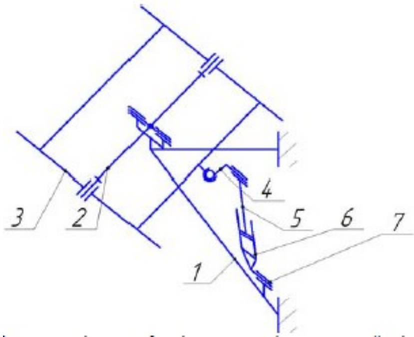

Fig. 2. Kinematic scheme of the tracker: 1 - a frame with an undercut; 2 - axis of the tracker; 4 - turntable; 5 - drive socket; 6 - drive housing; 7 - the hinge.

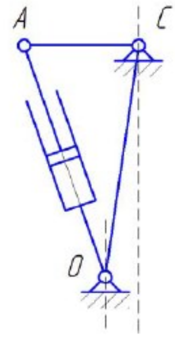

Fig. 3. Kinematic scheme of the executive mechanism.

For the purpose of maximum illumination in the light period of the day static and dynamic systems were installed strictly to the south with the same angle of inclination in the plane of the zenith. The general view of the installed photo modules is shown in Fig. 4. In the static and dynamic solar power stations, two 150 W solar panels are used each.

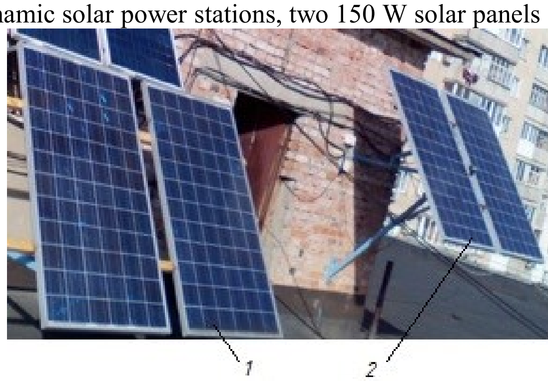

Fig. 4. General view of the installed photomodules: 1 - static; 2 – dynamically.

Output data for determining the optimal angles in the zenith plane is determined using a specially designed program. To do this, using the GPS module, the coordinates of the tracker's location were determined: the geographical latitude of the defined point is H 49.4066; geographical longitude is E 26.9639.

The actuator, illumination sensor and microcontroller for controlling the process of orientation of the modules were also selected.

To study the efficiency of solar power stations, a structural diagram of the stand, presented in Fig. 5, was developed. The block diagram in the center has a module for collecting and processing information Arduino Uno [8]. After processing, the signal is received through the Wi-Fi module, the Internet network on the computer. Signals are fixed by current sensors. Signals from sensors and voltage dividers enter the analog inputs of the data processing module, digitized, processed and transmitted to the computer in the way described below.

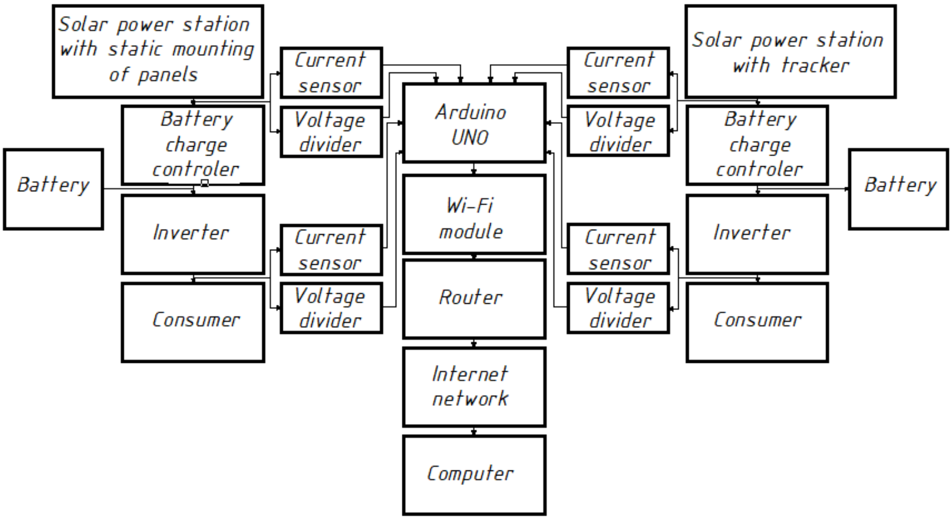

Fig. 5. The block diagram of the stand for the study of the efficiency of solar power plants.

On the basis of the structural scheme, an electric circuit diagram of the stand was developed and the necessary equipment was selected. The general view of the experimental stand is shown in Fig. 6.

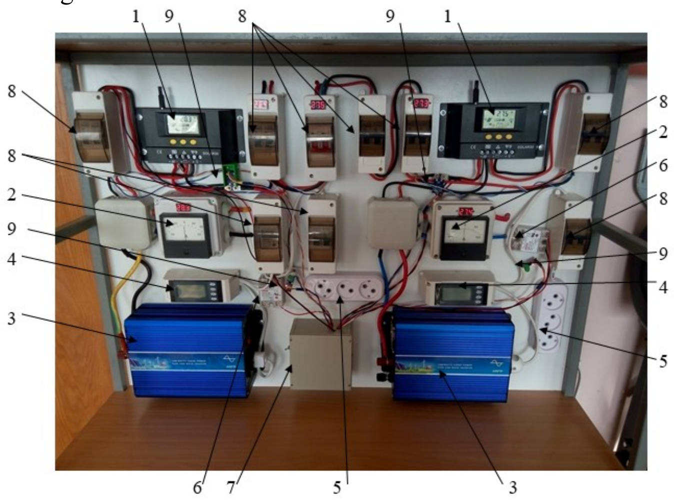

Fig. 6. General view of the experimental stand: 1 - battery charge controller; 2 - ammeter; 3 - inverter; 4 - Controller (contains a built-in display for displaying current and voltage output); 5 - socket for connecting the load; 6 - solid state relay; 7 - module for collecting and processing information with the built-in power supply; 8 - electric switch with overload protection and short circuit; 9 - current sensor.

A monitoring system for two independent solar power stations was also created. The created system of research of the effectiveness of solar panels with tracker and stationary panel placement system enables to automatically visualize parameters, perform data processing in real time, form databases and perform a comparative analysis of their operational efficiency. It also allows to remotely track settings that are fixed from anywhere in the world [9-11]. The developed system makes it possible to compare the efficiency of solar panels. The WEB page of the developed monitoring system is shown in Fig. 7.

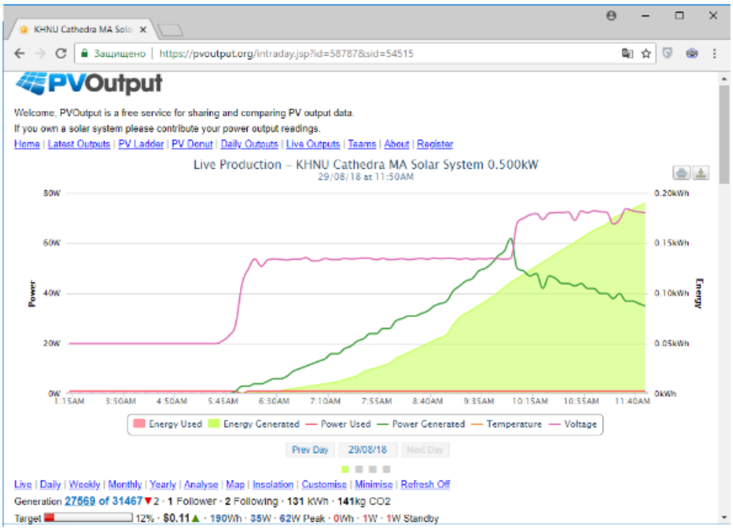

Fig. 7. WEB page of the developed monitoring system.

5 Results of experimental studies

Experimental studies were carried out in sunny and cloudy weather. Two days of sunshine, one sunny day and several days with different illumination of light day were chosen for the experiment. To ensure equal conditions of measurement, the solar panels of the two power stations were nearby, but the shade from the panels did not fall on one another. In the course of experimental research, the tracker system and data collection system worked in automatic mode. Data from photo modules was automatically removed and transferred to the server for plotting.

For the estimation of efficiency in numerical form, formula (1) used the percentage difference between two numbers:

$$a > b = ((a-b)/a) \cdot 100\% \tag{1}$$

where: *a* is the value of the first number; *b* is the value of the second number.

As a result of calculations, we obtain the percentage value that shows how one of the solar power stations is more efficient than the other over a certain period of time.

The first experiments were conducted on sunny and almost cloudless days (26 and 27 June 2018). Measurement of values was carried out at intervals of 5 minutes.

Fig. 8, 9 shows the received graphs from the WEB-page for two power stations.

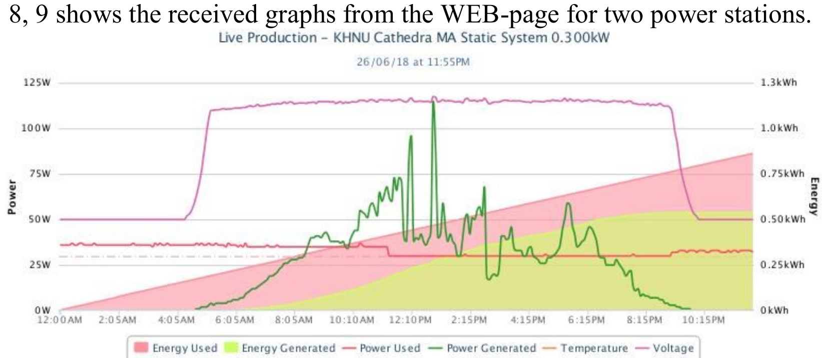

Fig. 8. Graphs of produced and consumed electric energy of a static solar power station as of 06.26.2018.

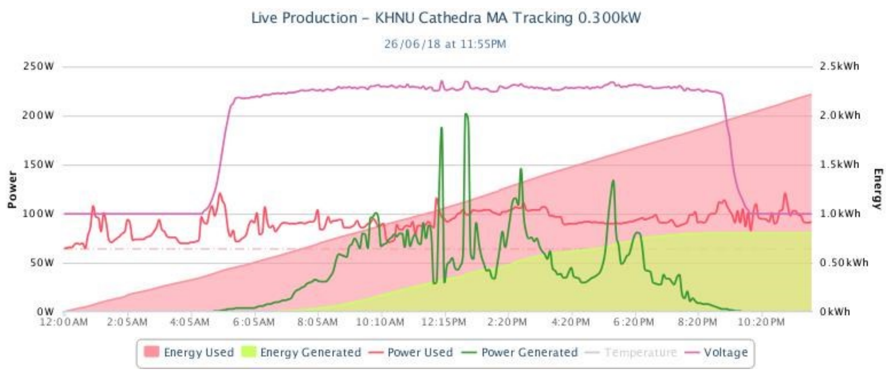

Fig.9. Graphs of produced and consumed electric energy of tracker solar power station as of 06.26.2018.

Total light day static system produced 0.537 kWh. The peak power at 12:55 am was 112 Watts. Over the course of the day a tracking system produced 0.806 kWh. The peak power at 12:55 am was 202 W, respectively.

For comparison, the combined graphs of electricity produced by two power stations were plotted (Fig. 10).

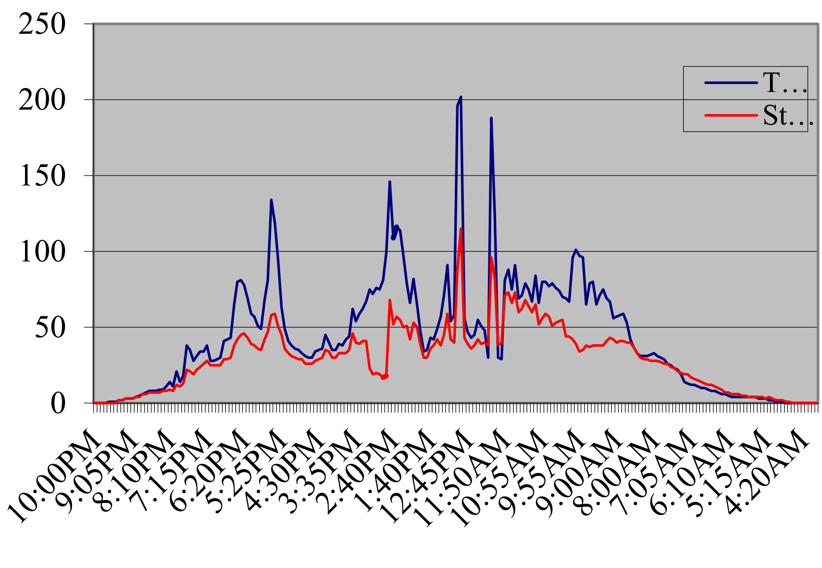

Fig. 10. Coherent graphs of produced electric energy of tracker and static solar power stations on 06.26.2018

Using formula (1), the effectiveness of the tracker system was calculated, which was 33.37%.

Next, experimental research was carried out on the following day (June 27, 2018) with a lower ambient temperature and solar activity, and the second half of the day was generally cloudy.

Having analyzed the received graphs, it was found that the static power station produced 0.336 kWh, and the tracker one 0.412 kWh. Maximum peak power reached 80 Watts and 167 Watts, respectively. Maximum solar activity was around 12 o'clock in the day.

The combined graphs of the produced electric power of both power plants are shown in fig. 11.

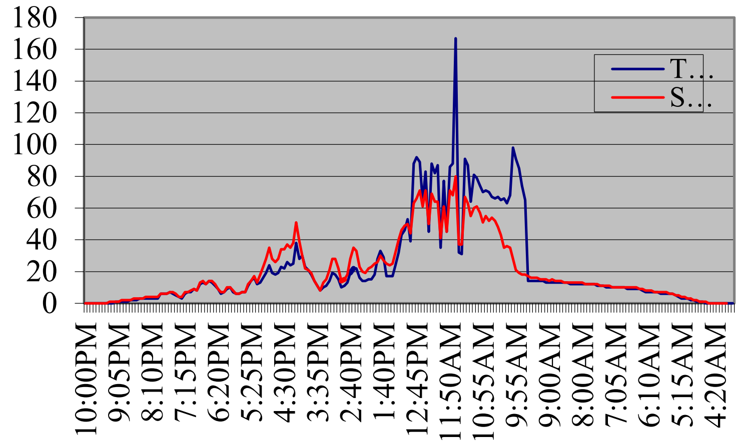

Fig. 11. Combined graphs of electric energy produced by tracker and static solar power plants on June 27, 2018.

The calculations carried out by the formula (1) show that on June 27, 2018, the tracker solar power station was 11.4% more efficient than the static.

The next experiment was conducted on September 13, 2018. On that day it was gloomy, there was no direct sunlight on the panel. The ambient temperature ranged from 16 to 20° C.

The obtained results (Fig. 12) showed that on that day, tracker and static solar power stations produced almost the same amount of electrical energy – 424 and 403 kWh, respectively. This is due to weather conditions, because the clouds in the sky prevented direct sunlight, and the illumination of the panel almost did not depend on the turn of the photo module.

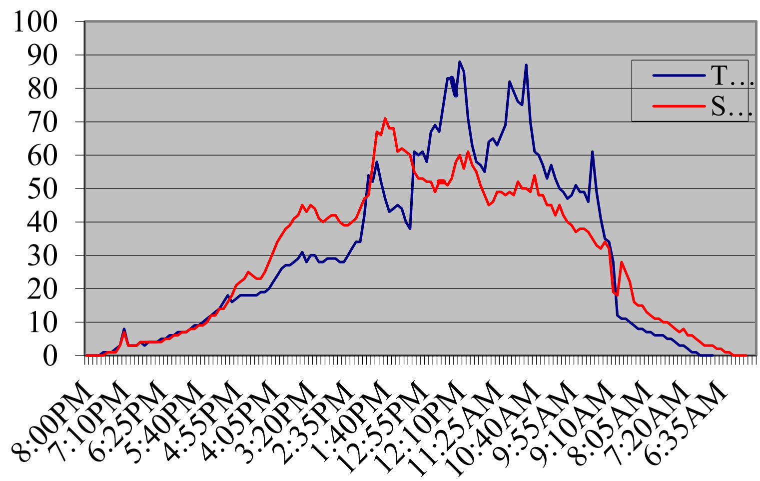

Fig. 12. Combined graphs of electric energy produced by tracker and static solar power station as of 09.13.2018.

The effectiveness of the tracker system on a cloudy day was 4.95%. The following experiment was conducted within three days from September 14, on September 16. These days were sunny, sometimes it was cloudy, but sunny activity was quite high. This experiment allowed us to evaluate the effectiveness of the tracker system over a long period of time. The largest amount of electricity was generated by solar power plants for these three days, 14.09.2018. Examples of the graphs received for this day are shown in Fig. 13, 14.

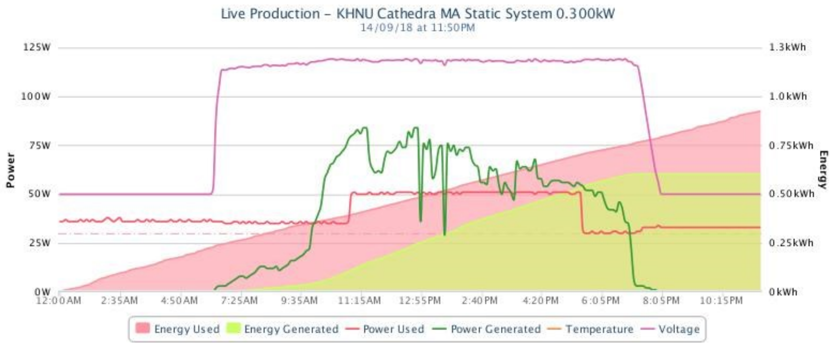

Fig. 13. Graph of produced and consumed electric power of static solar power station as of 09.14.2018, capacity 0,603 kW/h.

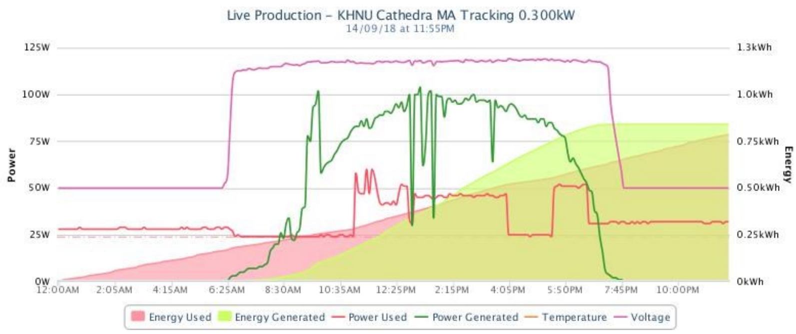

Fig. 14. Graph of produced and consumed electric energy of tracker solar power station as of 09.14.2018, capacity 0,841kW/h.

According to formula (1), the efficiency of the tracker power stations were compared with the static for 3 days. As a result of the calculations, it was 29.1%.

6 Conclusions

As a result of this work the design of a two-axis tracker with an automatic system of directing solar panels on azimuth during the light period of the day and with the possibility of manually adjusting the angle of rotation of solar panels on the zenith, depending on the season is developed. For the proposed design, the calculation of the angles of the zenith is made and the optimal angles are selected for manual adjustment of the seasonal positions of the system.

The developed solar power monitoring system is convenient at operation, enables to automatically visualize parameters, perform data processing in real time, form databases and perform a comparative analysis of their operational efficiency.

As a result of the experimental research on the determination of the produced electric energy of static and dynamic solar power stations, the efficiency of the tracking systems for the rotation of the solar panels was confirmed. The most effective tracker systems are in sunny weather. They can produce 33% more electrical energy than static under the same conditions. But with poor illumination of the panels (rain, fog, cloudy weather), the tracker's effectiveness decreases and it does not exaggerate 5% when fully covered with the sky. Therefore, the use of tracking systems in the absence of direct sunlight on the surface of photo modules is not feasible. In this case, the electric energy consumed by the tracker's drive may be greater than that which is additionally produced when solar panel follows the Sun.

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