

## COMPARATIVE INVESTIGATION OF FIXED AND TRACKING THE SUN SOLAR PHOTOVOLTAIC PANELS

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**Abstract.** The aim of the research is to investigate and compare the amount of electric energy obtained using stationary fixed, and tracking the sun in two axes photovoltaic panels. For that, two photovoltaic panels Solet P6.60-WF-250 were stationary mounted on a fixed stand and directed to the south at the angle of inclination  $42^\circ$  to the horizon. Another two photovoltaic panels of the same type and size on a dual axes automatic solar tracker ST44M2V4P were assembled. The experimental investigation has been carried out from June to December 2016. During the time in every 2 minutes, the developed electric power of both devices was registered and the results recorded using HOBO type data recorders. Graphics for each of the days showing the dependence between the solar radiation intensity and photovoltaic energy conversion were processed and analyzed. The sun tracking panels developed maximum of electric power in the autumn. So on October 11, 2016 at the outside air temperature  $4^\circ\text{C}$  their power reached 580 W and at the end of November at negative outdoor air temperature  $-2.2^\circ\text{C}$  they developed power up to 510 W. During summer hot days at the outdoor air temperature up to  $30^\circ\text{C}$ , the panels developed power 440-460 W. On the hot day June 11, 2016 the max power did not reach 90 W. During the time of the experimental investigation – 142 days, two stationary working photovoltaic panels Solet P6.60-WF-250 produced 254 kWh electric energy, but tracking the sun 384 kWh or 1.51 times more.

**Keywords:** photovoltaic panels, fixed and tracking stands, solar trackers, electricity.

### Introduction

Total energy production and consumption on the globe is continuously growing due to the worldwide increasing demand. At present, mainly fossil energy resources are used, such as crude oil and natural gas are leading to considerable damage of the earth environment, and their amount is limited. Therefore, in many countries, particularly in the southern ones from year to year scientific investigation and practical implementation of appliances for the use of such alternative energy source as solar energy are growing. Mainly they are photovoltaic panels, producing electricity and solar collectors for domestic water heating [1-3].

In order to obtain the maximum of electric or heat energy, solar beams have to strike the solar radiation receivers – photovoltaic (PV) panels or collector absorber surface perpendicularly. Otherwise, depending on the cosine of the angle of the solar radiation incidence, part of solar energy is lost. The loss part of the direct solar radiation power  $\Delta P$  depending on the angle  $\varphi$  between the normal of the solar incidence intercepted surface and solar beams direction, is calculated as  $\Delta P = 1 - \cos\varphi$  [4]. To avoid that, special devices – trackers are used. A solar tracker is a device that orients a payload – PV panels toward the sun.

Solar energy receivers – collectors and panels depending on the way of mounting them on their stands, can be divided into three groups: stationary located or fixed, tracking the sun in one axis and tracking the sun in two axes. It is possible to produce considerably more energy mounting PV panels on stands, tracking the sun in two axes. It means that for a stationary placed photovoltaic panel the angle of perceptibility of the solar radiation is not greater than 180 degrees, and at the deviation of the solar beams striking the angle from the intercepted surface normal by  $\pm 60^\circ$ , the losses of the produced power is 50 %. Therefore, in practice the sun tracking stands with mounted on them photovoltaic panels are used more widely. Such panels can produce more and higher quality electric energy, because the solar radiation receivers are working at full capacity and considerably longer time during a day. Using the one axis solar tracing stand, the receiver of the incident usually is equipped with a solar energy concentrator, which allows obtain the solar incidence concentration degree from 10 to 85. It is possible to obtain the solar incidence concentration degree considerably higher – from 600 to 2000, if two axes solar trackers are used [5].

In order to specify how more electric energy can be obtained in Latvia latitude ( $57^\circ$ ) by PV panels, mounted on the sun tracking stand, in comparison with stationary fixed panels, an experimental investigation was carried out.

The aim of the research was to investigate and compare the amount of electric energy, produced by PV panels, stationary fixed and tracking the sun in two axes.

### Materials and Methods

In order to popularize the use of solar energy as well as for research and studies, in 2015 at the Latvia University of Agriculture Ulbroka Research Centre a dual – axis solar tracker ST44M2V4P with 4 PV panels Solet P6.60-WF-250 was obtained. In order to perform the investigation two PV panels were stationary mounted on a fixed stand, placed on the roof of a house, and directed to the south at the angle of inclination  $42^\circ$  to the horizon. Another two PV panels of the same type and size on a dual axes automatic solar tracker ST44M2V4P were assembled. The appliance consists of:

- solar tracking device ST44M2V4P in two axes with a stand (post);
- control unit "Sat Control";
- 4 solar photovoltaic panels Solet P6.60-WF-250;
- 4 solar micro-inverters Enphase M215.

Total power of the appliance is 1.0 kW, active absorber area –  $7.7 \text{ m}^2$ .

The photovoltaic panels of the dual axes solar tracking device ST44M2V4P are mounted on a frame, which in relation to the post is possible to turn around two axes – in the azimuth and zenith plane. For turning and orientation the panels to the sun, two linear electric motors SM4S520M2US with the length of the push bar move 520 mm were used. When the motor is operating, the length of the push bar changes. The angle between the frame and the axis, around which the turning is taking place, changes too. One of the motors of the device turns the frame with the panels around an incline axis in the north direction, changing the azimuth angle. Another motor changes the angle between the incline axis and the horizon. In such a way the panel frame is tracking the sun in the zenith plane. Both of the motors are operating successively according to the adjusted time span under the control of the control unit "Sat Control".

In order to adjust the operation of the appliance ST44M2V4P at first it was mounted in a laboratory with two photovoltaic panels Solet P6.60-WF-250. The appliance was connected to the electric grid of 24V, and the solar tracking control unit "Sat Control" was connected to a computer. According to the appliance operation instruction, in the computer a driver was installed and the monitoring table was opened. In the gaps of the table the demanded data were inscribed: the coordinates of the place, date, time and others. If the device is ready for operation and the gaps of the table filled correctly, the device automatically orients the sun and starts its tracking. The device provides the sun-tracking angle in the range of 90 degrees. In summer time the consumed current of two motors turning the device with two photovoltaic panels is up to 0.2 A. According to the instruction, the maximum motor current is 0.5 A, voltage  $24 V_{DC} \pm 10$  percentage and current in the outgoing electric circuit is not more than 2 A. From our experience, for the device motor stable operation it is important to ensure that electric resistance in its feeding circuit is sufficiently small.

To perform the objective of the research, the following tasks are to be set: to place the experimental appliances on the roof of a house and adjust their operation; to measure and record the electric energy output by both PV panel systems and to process and analyze the obtained experimental results. In order to perform the objective of the research two PV panels Solet P6.60-WF-250 were fixed stationary on a special stand and the dual axes solar tracking device ST44M2V4P with a stand and two PV panels Solet P6.60-WF-250 mounted on it were placed on the roof of a house (Fig. 1). The fixed panels were oriented in the south direction with the angle of inclination to horizon was  $42$  degrees. Considering the recommendations from literature [1] the angle of inclination of the solar panels  $\alpha$  to the horizon has to be calculated as

$$\alpha = \varphi - 15^\circ = 57^\circ - 15^\circ = 42^\circ,$$

where  $\varphi$  – latitude of the place, degree (for Riga  $\varphi = 57^\circ$ ).

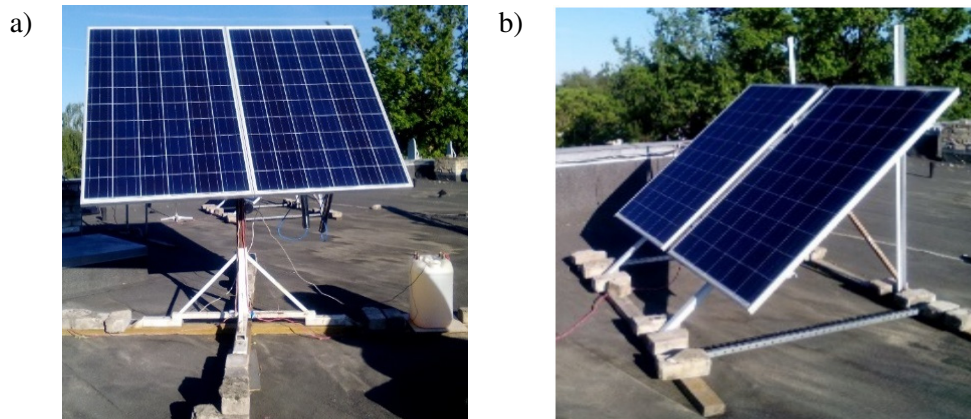


Fig. 1. PV panels Solet P6.60-WF-250 on the roof of a house:  
a – tracking the sun; b – stationary fixed

In order to achieve the tasks set for the panels working in a fixed position and tracking the sun mode, the developed by the panel's power was measured and recorded using HOBO type data recorders. The scheme of data recording is shown in Fig. 2.

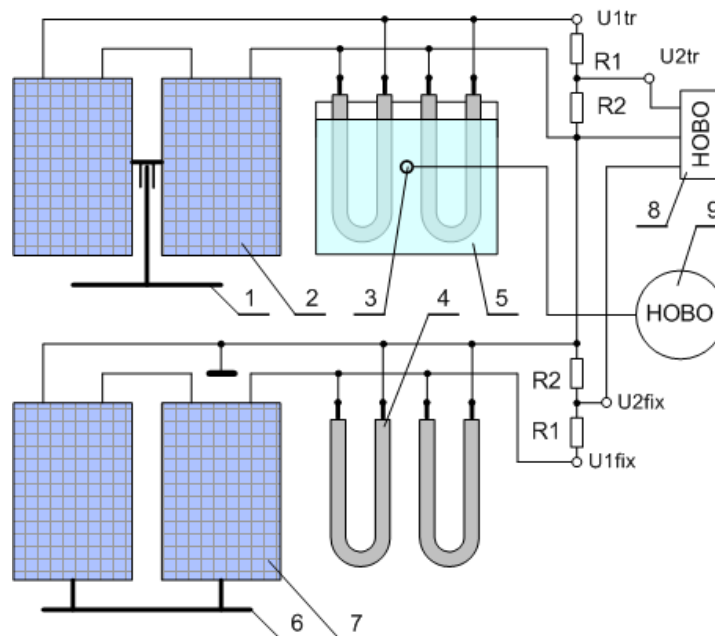
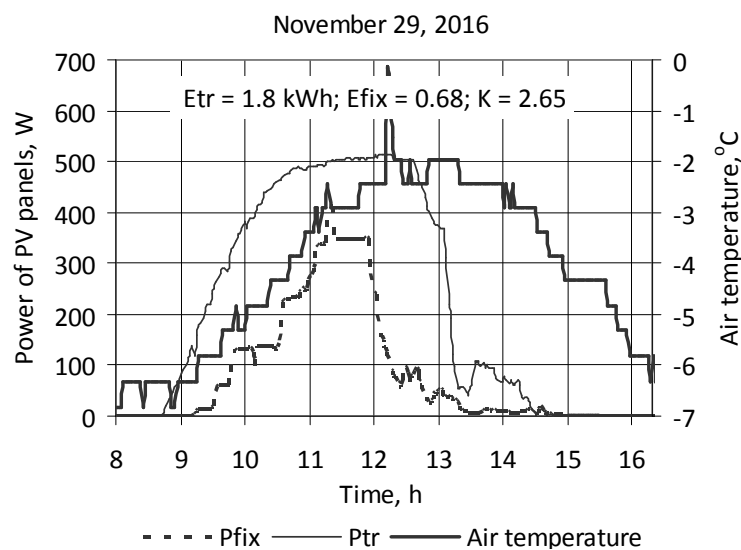


Fig. 2. **Scheme of data recording:** 1 – stand of sun tracking devise; 2 – panels on sun tracking device; 3 – temperature sensor of data registration HOBO; 4 – water heaters,  $R_L = 10.5 \Omega$ ; 5 – water basin; 6 – stand of fix device; 7 – panels on fix device; 8; 9 – data recorder HOBO;  $R1$ ;  $R2$  – voltage divider resistors;  $U1$  – voltage on two in series connected panels clamps;  $U2$  – voltage on data register clamps

For the data recorder HOBO is shown the maximum operating voltage value is 2.5 V, but for two in series connected PV panels Solet P6.60-WF-250 the ideal running voltage  $U1 = 38.4 \cdot 2 = 76.8$  V. Therefore, in order not to overload the data register circuit, a voltage divider from resistors  $R1 = 62 \text{ k}\Omega$  and  $R2 = 2.2 \text{ k}\Omega$  was used. The ratio of voltage division  $Kv = R2 / (R1 + R2) = 2.2 / (62 + 2.2) = 0.034$ . The voltage  $U2$  on the data registers clamps is calculated as  $U2 = U1 \cdot Kv = 76.8 \cdot 0.034 = 2.61$  V, what is by 0.11 V more than needed. In the data register circuit, there is a certain electric resistance. When the data register is connected to the voltage divider, this resistance in series becomes connected to the resistance  $R2$ , what decreases the common resistance and voltage  $U2$  on the data register. Therefore, the actual values of the voltage division ratio were determined measuring the voltage  $U1$  and  $U2$  values using the multi-meter FINEST 707, with data recorders connected to the voltage divider. It was obtained that for the fixed panels  $Kv_{fix} = 1.83 \text{ V} / 62.4 \text{ V} = 0.029$ , but for the tracking the sun device  $Kv_{tr} = 1.92 / 63 = 0.03$ , and the system is ready for operation.

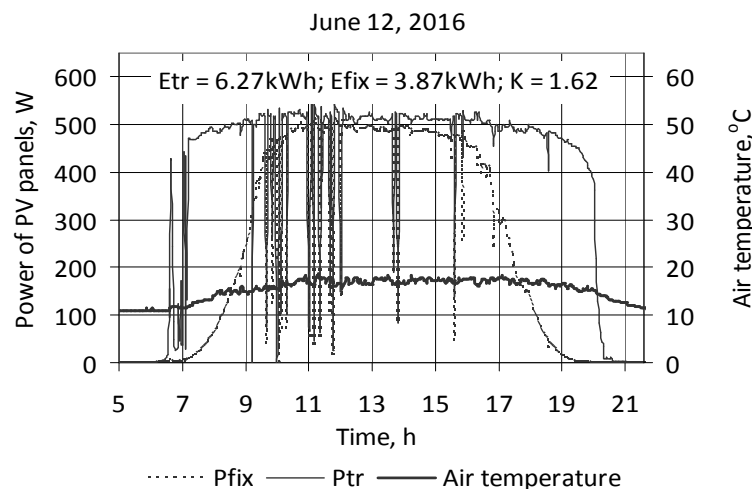
**Results and discussion**

For both working in fixed and tracking the sun modes PV panels developed electric power has been registered and graphs obtained in every 2 minutes, starting from June until December 2016. Maximum of electric power had developed in the autumn, October 11 – 580 W, at the outdoor air temperature +4 °C. It was stated, that with VP panels working in tracking the sun mode higher power is possible to obtained in late autumn and winter months (Fig. 3), when at the end of November at the outdoor air temperature –2.2 °C the developed power was 510 W. From the graphs on October 11, 2016 it is seen that tracking the sun PV panels during 10 hours have developed nominal power 500 W. Power around 500 W of panels working in tracking the sun mode has developed on September 16, 2016, but during shorter time. From the obtained curves it follows that tracking the sun panels during summer months (June, July and August) have developed lower power 440-460 W, what is less than nominal. That can be explained by the high outdoor air temperature (up to +30 °C). During summer time in some days maximum of the developed power did not reach even 90 W. From the obtained curves it follows that the panels working in a fixed position have developed less power in comparison with the panels working in tracking the sun mode due to their static position and worse operation conditions.



**Fig. 3. Power P and electric energy E produced by PV panels on November 29, 2016:**  
ratio  $K = E_{tr}/E_{fix}$

Analyzing the operation time of the panels it follows that 50 % of the maximum power tracking the sun panels on June 12 (Fig. 4) developed during 13.5 hours from 6:30 to 20:00, but of the fixed panels during 8 h and 20 minutes from 9: to 17:20, or by 5 h and 10 minutes less.



**Fig. 4. Power P and electric energy E produced by PV panels on June 12, 2016:**  
ratio  $K = E_{tr}/E_{fix}$

Smaller difference in the operation time length is in the autumn. For instance, in October 11 the difference is only about two hours, when tracking the sun PV panels have operated for 9 hours. Using the data on the registered power, we have calculated the produced amounts of electric energy (Table 1).

From the experimentally obtained data, it is seen that the PV panels working in tracking the sun mode are able to produce more energy than the panels working in a fixed position, because the solar radiation is striking them perpendicularly and they have better cooling and self-cleaning conditions.

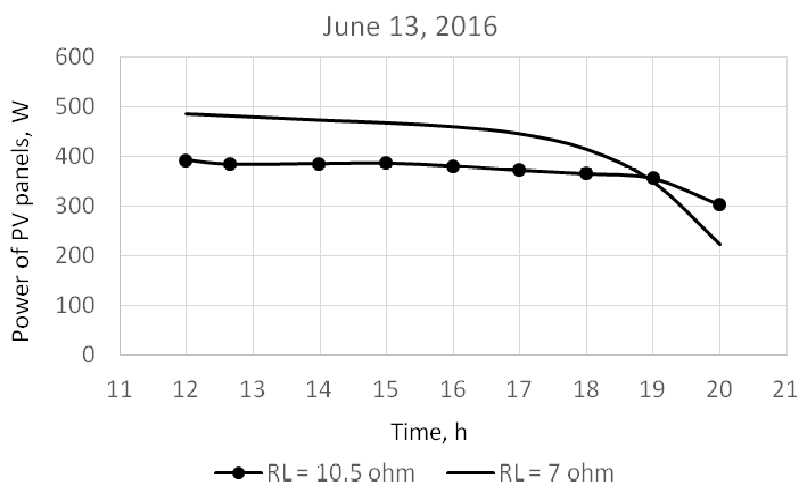
Table 1

**Energy produced by fixed and tracking the sun PV panels**

Months, 2016	Days	$E_{fix}$ kWh	$E_{tr}$ kWh	Ratio $E_{tr}/E_{fix}$
June	30	68.0	109.1	1.60
Average per day		2.27	3.64	1.60
July	31	62.3	95.8	1.54
Average per day		2.01	3.09	1.54
August	31	53.4	78.4	1.47
Average per day		1.72	2.53	1.47
September	30	39.2	55.1	1.40
Average per day		1.31	1.84	1.40
October	20	30.1	45.8	1.48
Average per day		1.55	2.29	1.48
Total	142	254.0	384.0	1.51
Average per day		1.79	2.70	1.51

$E_{fix}$  – energy produced by fixed panels;  $E_{tr}$  – energy produced by tracking the sun panels.

At constant external electric resistance of a PV panel, its developed power depends on the intensity of solar radiation [2], which during a day is changing from 0–1000 W·m<sup>2</sup>. In order to establish the optimum of the external load  $R_L$  for panels Solet P6.60-WF-250, during the clear sunny day on June 13, 2016 they were loaded with the external load 10.5 Ω and 7.0 Ω. For that, the panels were connected to the resistances, using two and three electric heaters placed in a basin of water. As it is seen from Fig.5, the resistance curves intersect at 360 W. It means that panels operating at the power higher than 360 W can produce more electric energy, if the external resistance is 7 Ω. If the panel external resistance is 10.5 Ω, more energy is produced at its electric power less than 360 W.



**Fig. 5. Power of tracking the sun panels depending on load resistance  $R_L$**

It is possible to produce more energy, when panels are loaded with external resistance less than 10.5 Ω.

## Conclusion

1. PV panels working in tracking the sun mode have produced more electric energy than panels working in a fixed position, because the radiation strikes their absorbing surface perpendicularly, during a day they work longer time and have better cooling and self-cleaning conditions.
2. Maximum power 580 W has been produced by tracking the sun panels in the autumn (October 11, 2016) at the outdoor air temperature 4 °C.
3. Power developed by tracking the sun PV panels on clear winter day (November 29, 2016) at negative outdoor air temperature can be similar or higher than produced in summer time.
4. In summer, there are days when the maximum power produced by panels does not reach 90 W (June 11, 2016).
5. In summer months like June 12, 2016 tracking the sun PV panels with power 250 W have been working for 13.5 hours, but fixed panels only for 8.33 hours, what is by 5.17 hours less. In the autumn months this difference is smaller. So, on October 11, 2016 it made only 2 hours.
6. During 142 days of the experimental investigation, the fixed PV panels have produced 254 kWh electric energy, but tracking the sun panels 384 kWh, what is 1.51 times more.
7. In order to produce the maximum amount of electric energy during a year, at making a stand for fixed panels, it is necessary to anticipate the possibility for adjusting a different angle of the panel inclination in spring, summer and autumn months.

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