Agronomy Research Biosystem Engineering Special Issue 1, 227-234, 2012

Experimental investigation of photovoltaic-thermal hybrid solar collector

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Abstract. From August 6 2011 till September 29 2011 an experimental investigation of hybrid classic photovoltaic-thermal solar collector MWPVT-1414 was carried out. The hybrid solar battery had produced 23.01 kWh of electric energy during 55 days of investigation, or 0.418 kWh per day on average. It was calculated that during the summer months from March 1 till November 1 the amount of electric energy produced by the battery could be about 100 kWh. The highest cooling water temperature was 43°C, which is 16°C higher than the surrounding air temperature.

Key words: hybrid solar collector, battery, power, temperature.

Introduction

Photo electric convertors or modules are used for direct conversion of solar radiation into electric energy. They consist of separate semi-conductors, called photo electric or solar elements or cells, connected in a series. The number and size of cells depends on the required current intensity and the voltage value. Solar batteries or panels are made by connecting photo-electric modules in series and/or in parallel. More widely used are silicon (Si) solar elements and independence of the production technology they can be mono-crystalline (c-Si), poly-crystalline (pc-Si) and amorphous. The energy conversion coefficients for these elements are 12–15, 11–14 and 6–7 accordingly. For the poly-crystalline group thin film elements are also added.

Photovoltaic batteries convert solar radiation partially: to electricity and to heat. The peak of the electric efficiency is in the range of 5–20%, depending on the type of photovoltaic cell. The remaining energy from the solar radiation is absorbed into the panel's material, which leads to an increase of the panel's temperature and accordingly to a decrease of efficiency. This decrease for amorphous silicon cells (a-Si) is about 0.25% per degree rise in temperature, but for mono-crystalline (c-Si) and polycrystalline (pc-Si) silicon solar cells it is about 0.45% for every degree rise in temperature. Naturally, in order to keep the panel's electric efficiency high, its temperature has to be kept low enough, removing the heat produced by the absorption of solar radiation.

In practice it is performed by coupling the PV panel with the heat extraction unit, usually an ordinary flat plate solar collector is connected with one hybrid photovoltaic-thermal (PVT) system. Such a hybrid solar collector produces both electric and heat energy. The photovoltaic module rear surface is in direct thermal contact with the solar collector's metallic heat absorbing plate, which removes the heat from the PV module. Heat is removed from the solar collector by the heat transfer medium, which is circulating (by force) through the collector's pipe-type heat exchanger.

In PVT system applications the main priority is the production of electricity, therefore it is more important to operate the PV modules at a low temperature to keep PV cell electrical efficiency as high as possible. The PV module and solar collector are enclosed in a metallic or plastic casing. In order to reduce thermal losses a layer of heat insulation is installed at the back and side surfaces inside the casing. The front side of the casing is covered by a transparent glass or plastic cover, to avoid heat loses from the front side.

The PV panel can be cooled by an air flow too, but if the surrounding air temperature is high (above 20°C) the efficiency of such a cooling system will be low. For a more sensible effect it is advisable to use a PV cell solar collector cooling unit, where as for the heat carrier some non-freezing fluid is used (water is not suitable for cases when the surrounding air temperature is under zero degrees).

The objective of the research is to discover the usefulness of the use of hybrid solar collectors in Latvian meteorological conditions, as when comparing them with ordinary solar batteries their construction is more complicated and the price is quite high.

Materials and methods

Experimental investigation of photovoltaic-thermal hybrid solar collector MWPVT–1414 has been carried out. Such a collector consists of a solar cell battery (electricity production) and a solar collector (water heating). Therefore the hybrid solar collector is simultaneously conversing solar radiation into electricity and heat. It is a known fact that during the battery operation its temperature rises, because only a part of absorbed solar energy is converted into electricity - the biggest part of the solar radiation energy is converted into heat. The efficiency of electricity production decreases when the solar battery's temperature rises. Therefore it is purposeful to cool the battery at high surrounding air temperatures.

The hybrid solar collector having the face area 1.1 m^2 and solar radiation transfer coefficient 15% was placed on the roof of a house. In order to meter the electric power produced by the battery a special electric power metering block was developed and connected to the experimental battery (Latvian patent LV 14165). The output of electric current was measured by the block in a certain period of time and recorded in a HOBO type data logger. The amount and the temperature of water circulating in the solar collector were metered and recorded simultaneously. The analysis of obtained results shows the effect of the battery's cooling at different surrounding air temperatures.

Only about 12–15% of solar radiation striking mono- and poly-crystalline photoelectric panels' surfaces is converted into heat. The rest of the solar energy is reflected from the panel's surface and undesirably warms the photoelectric element leading to the decrease of the efficiency and lifetime of the panel. If the temperature of the mono- or poly-crystalline panels rises 1°C above 25°C, voltage on the clamps decreases by 0.4% on every 1°C (http://www.solar.alisen.ru/solhybrid.php). Decrease of voltage for the thin film panels is two times less. In Fig. 1 the fall of efficiency of a mono-crystalline element when its temperature rises from 25°C up to 60°C is shown, and a cross section of a water cooled hybrid solar battery in Fig. 2 is presented as well. If the element is loaded at an optimal load, it means the load is adjusted by the coherence U · I = P_{max}, decrease of the power is from 3.53 W to 2.84 W what is by 19.5%. However, if the photo element is loaded with constant additional electric resistance, at which the maximal value of the load power is in point 3 (Fig.1) of the characteristic line of the power, then at the temperature rise of the photoelectric element from 25°C to 60°C, its power will drop from 3.53 W to 1.27 W, what is by 64%. It means that, firstly, it is possible to produce more electricity by the solar battery cooling and, secondly, the obtained hot water or hot air can be used for other purposes (heat energy). To carry out the described process the classic solar battery and flat plate solar collector are mounted into one casing and this device is called solar hybrid battery or collector.

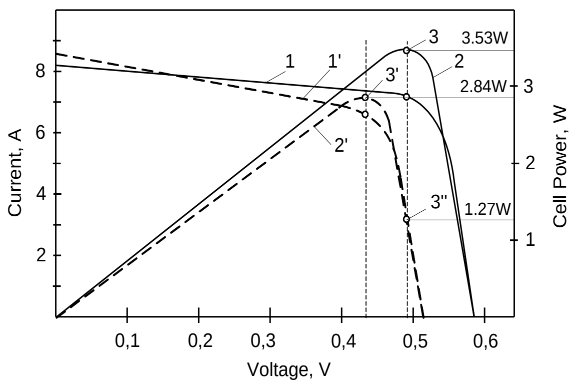


Fig. 1. Decrease of mono-crystalline photo-element electric production efficiency at its temperature 25°C and 60°C: 1; 1′ – volt-ampere characteristic; 2; 2′– power characteristic; 3; 3′ – optimal loading power points (U · I = P_{max}); 3″ – power of the photo-element at 60°C, when loaded with contact load resistance, numerical value is optimal in point 3 on the characteristic line.

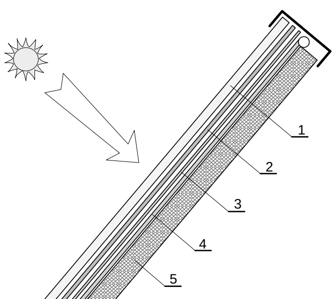


Fig. 2. Cross section of a water cooled hybrid solar battery: 1 – glass cover; 2 – photo-voltaic panel; 3 – copper sheet; 4 – heat extraction canals (copper tubes); 5 – heat insulation; 6 – heat carrier inflow and outflow (on the top) manifolds; 7 – casing.

At calculation of the hybrid solar batteries parameters the following mathematical coherences were used. Thermal parameters of the battery were calculated as (Harcenko, 1991)

$$P_s = g \cdot c_p (T_2 - T_1), \tag{1}$$

where P_s – power of the module, W;

g – intensity of the heat carrier flow into the heating element, kg s^{-1};

c_p – specific heat capacity of the heat carrier, J kg^{-1}°C^{-1};

T_2 ; T_1 – outflow and inflow heat carrier temperature, °C.

If the intensity of the heat carrier flow g in kg h^{-1} is given and the heat carrier water is used, (c_p = 4.18 J kg^{-1}°C^{-1}), the power is being calculated as

$$P_s = 1.161 \cdot g \cdot (T_2 - T_1)\,. \tag{2}$$

If the heat produced by the device is being stored, then an accumulated amount of heat energy can be figured as

$$Q = m \cdot c_p (T_2 - T_1)\,, \tag{3}$$

where Q – produced amount of heat energy, kJ; *m*– heat carrier mass, kg.

If a battery is loaded with the constant load resistance, its power is calculated as

$$P_c = \frac{U^2}{R} \text{ or } P_c = I^2 \cdot R\,, \tag{4}$$

where U – voltage, V; R – resistance, Ω.

Cooling a battery by water can be effective only in places with a high surrounding temperature (at small latitudes). For carrying out the experiment on the roof of a house the solar hybrid battery MWPVT-1414 was installed (Fig. 3) with its accessory parts; 1– hybrid battery, 2 – water circulation pump, 3 – water receptacle (30 litres), 4 – heat meter (M-CAL compact 0.6). The hybrid battery has been electrically loaded with 10 Ω resistance. At nominal voltage 35.3 V the electric power produced by the battery was P_e= 125 W, which is less than its rated capacity.

For the produced electric power recording, the data recording device HOBO Data Logger H08-006-04 was used (Fig. 4a). The logger was fixed to a box which was provided with voltage and power indicators, but for metering such meteorological parameters as air temperature and power of solar radiation on stationary (at the south oriented) and tracing (the sun surfaces) the movable meteorological data metering and recording device MMD-4 (Latvian patent LV 14312, 2011, Putans *et al.*, 205) was used (Fig. 4b), where for the data recording HOBO Data Logger H08-006-04 was also installed.

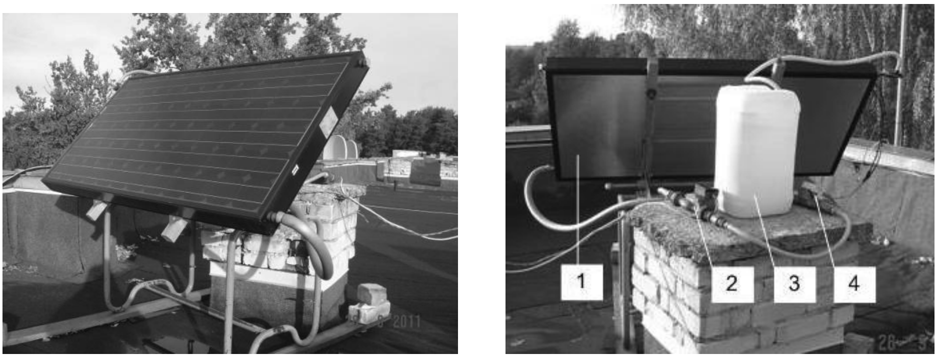
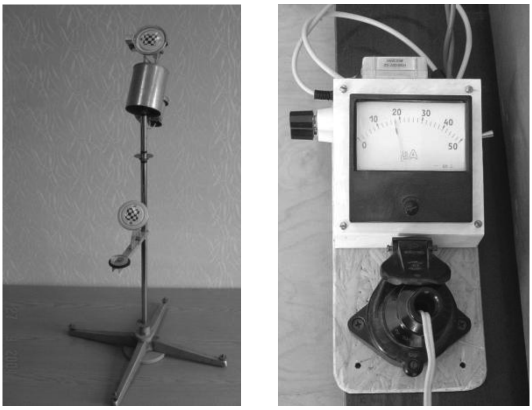


Fig. 3. Hybrid solar battery MWPVT-1414 on the roof of a house (front and rear side): 1 – hybrid battery, 2 – water circulation pump, 3 – water receptacle (30 litres), 4 – heat meter (M-CAL compact 0.6).



a b

Fig. 4. a – Data recording device HOBO Data Logger H08-006-04, b – Device MMD-4.

The hear meter M-CAL compact 0.6 used in the experimental investigation was not supplied with any automated data registration possibility. Therefore, thermo-technical parameters of the battery such as inflow and outflow heat carrier temperature periodically were read and registered manually. This was quite a labour consuming process. Therefore for the following investigation it is envisaged to supply the solar battery loop with an automated thermo-technical parameters metering and recording device, allowing the acquisition of all experimental parameters automatically and synchronously.

Results and discussion

The experimental investigation of the hybrid solar battery was carried out from August 6 till September 29, 2011. With uninterrupted 5 day periods and time intervals of 5 minutes the electric power P_e produced by the battery was measured and registered. In certain favourable heat energy production days the intensity of solar radiation, produced hot water and surrounding air temperature were measured. The battery's electric power P_e as a function of solar radiation intensity E_e during a clear sunny day, when the battery's cooling system was operating in Fig. 5 is presented. As is seen, the maximum value of electric power produced by the solar battery is about 120 W, when the cooling heat carrier was relatively cold. Later, at a warmer heat carrier, the battery's electric power was dropping off. In Fig. 6 the electric power produced by the solar battery during the experimental period is presented.

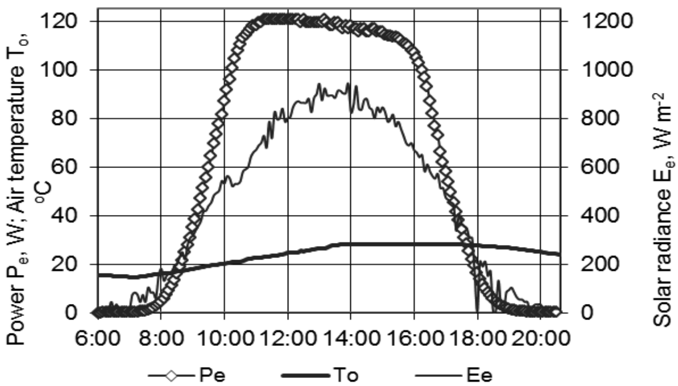


Fig. 5. Dependence of produced electric power by the solar battery MWPVT-1414 on solar radiation intensity, August 27, 2011.

Using expression (3) the amount of electric energy produced by the solar battery was calculated. It is stated that during 55 days the hybrid solar battery MWPVT-1414 has produced 23.01 kW·h of electric energy, or on the average 0.418 kW·h per day. It means that in total during the summer months of a year from March 1 till November 1 the amount of electric energy produced by the battery could be about 100 kW·h.

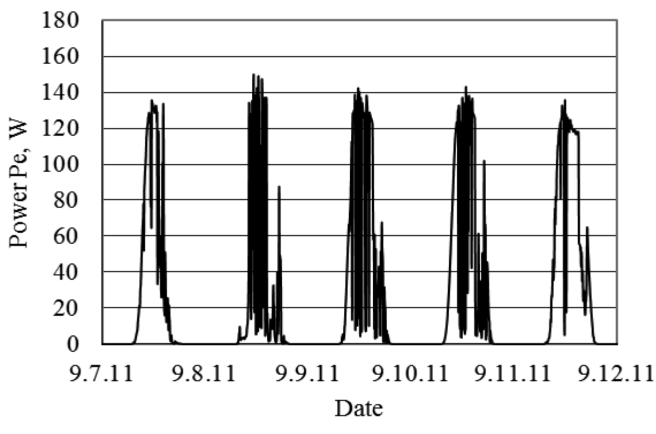


Fig. 6. Electric power P_e produced by solar battery MWPVT-1414 during 5 days.

Electric power P_e produced by the battery, heat power P_w, heated water temperature T_w and outdoor air temperature T_o in Fig. 7 are shown. As is seen, during 4.5 hours the water temperature had risen from 18 to 32°C or by 14°C. At the same time the rise in outside air temperature was only from 12 to 18°C, that is, by 6°C. The difference between water and air temperatures did not exceed 14°C.

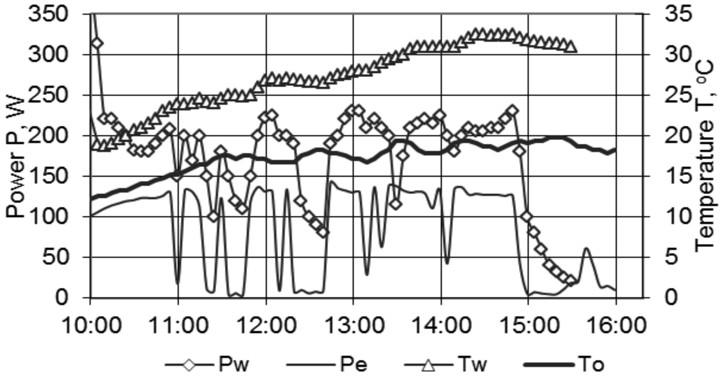


Fig. 7. Electric power (1) P_e produced by the hybrid solar battery MWPVT-1414 depending on heat power (3) P_w, cooling water temperature (4) T_w and surrounding air temperature (2) T_o.

It was stated that during cloudy days the amount of electric energy produced was higher than in clear sunny days, because of additional solar radiation reflected from clouds.

Maximal electric power produced was about 140 W, but heat power was about 230 W, which is 1.6 times more. It should be noted that in all experiments heat power was bigger than electric power, but no more than 2 times. It can be explained that experiments were carried out at the end of the summer. As the battery MWPVT-1414 from the water heating point of view is a collector without the cover, and the experimental system was not thermally insulated, some part of heat energy was lost to surrounding air. Therefore with such a system it is possible to obtain only low temperature hot water, the main task of which is to cool the battery. The highest water temperature measured on August 15 at 15:00 was 43°C, which is 16°C higher than the surrounding air temperature.

It should be noted that the controversial system is obtained after a combination of a solar battery and solar collector. For the solar battery it is desirable that the cooling water temperature is relatively low, but for the solar collector it is preferable to obtain a water temperature higher than 60°C. In order to avert this contradiction, in bigger hybrid batteries' applications it is advisable to use the heat pump principle, as it makes it possible to gain heat energy from the low temperature cooling water.

It is proposed to continue the investigation in summer 2012 using more developed equipment.

Conclusions

1. Experimental investigation of hybrid classic solar battery MWPVT-1414 was carried out from August 6 2011 till September 29 2011 (55 days) during which the battery has produced 23.01 kW·h electric energy or 0.418 kW·h per day on average.

2. During the experimental investigation the highest cooling water temperature of 43°C was stated on August 15 at 15.00, which was 16°C higher than the surrounding air temperature, but the highest electric power produced by the battery 156.5 kW·h was recorded on September 8 at 12.45.

3. Heat power produced was higher than the electric power produced during all of the experimental investigation, but this ratio did not exceed 2.

4. A controversial system is obtained after a combination of a solar battery and solar collector. It is desirable that the solar battery cooling water temperature is relatively low, while for the solar collector it is preferable to obtain a water temperature higher than 60°C. This is impossible to realize simply by circulating the cooling water. Instead, it is advisable to use a heat pump principle to make the hybrid device work more efficiently.

ACKNOWLEDGMENTS. Research is completed by financial support of European Structural Fund: Attraction of human resources for investigation of renewable energy resources. Realized by the Project Department of Latvia University of Agriculture (contract no. 2009/0225/1DP/1.1.1.2.0/09/APIA/VIAA/129).

References

Harcenko N.V. 1991. *Individual solar appliances*. Энергоиздат, Moscow, 208 pp. (in Russian).

General information about solar hybrid batteries'. Available at http://www.solar.alisen.ru/solhybrid.php. Last accessed in 23.01.2012 (in Russian).

Putans, H., Putans, A., Iljins, U., Pelece, I., Zagorska, V., Kancevica, L., Ziemelis, I., Jesko, Z., & Ilsters, A. 2010. Device for solar battery power registration. Latvian patent LV 14165. In: *The Official Gazette of the Patent Office of the Republic of Latvia.* **6/2010**, pp. 886–887 (in Latvian).

Putans, H., Zagorska, V., Ziemelis, I. Mobile meteorological data registration device (2011): Latvian patent LV 14312. In: *The Official Gazette of the Patent Office of the Republic of Latvia*. **4/2011**., p. 491 (in Latvian).

Putans, H., Ziemelis, I., Putans, A. & Ziemelis, E. 2005. Removable device for measuring and registration of metereological parameters. In: *Proceedings Engineering Problems in griculture*. Jelgava, Latvia, pp. 222–227 (in Latvian).