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ANALYSIS OF PHOTOVOLTAIC CELLS USAGE IN A HOUSEHOLD

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ABSTRACT

The issue of photovoltaic cells usage for hot tap water heating in a household has been presented. There has been built a research point, which was situated on a single-family house in the country. The aim of the research was obtaining maximum performance characteristics of the system for hot tap water heating based on photovoltaic cells. It was carried out during summer solstice because of the most favourable relationship of day versus night, from the point of view of efficiency. Results collected from the research enabled to obtain a lot of exploitation characteristics describing the system. There have been presented exemplary time courses of action of generated power and selected working parameters. Maximum energy performance of the system has been determined. Further research should enable to define minimum hot water tank capacity as a buffer of energy and minimum number of panels that constitute a heating water battery, in order to fulfil requirements included in the Ordinance of the Minister of Infrastructure dated 14th January 2002, related to defining average norms of water consumption (Journal of Law 8/02 item70).

Introduction

Development of renewable sources of energy in Poland is an activity, the aim of which is taking care of environment cleanness and improving energy stability of the state. Strategic document in the scope of energy development in the state is „The Energy Policy of Poland till 2030" adopted by the Government on 10th November, 2009. One of the priorities of the strategy is increasing by Poland till 2020 the share of energy obtained from renewable sources of energy to the level of at least 15%. The obligation to reach the aim mentioned above is the result of the regulation 2009/28/EC related to application of energy obtained from renewable sources of energy. It is a particularly significant problem, since 87% (53.8% hard coal, 33.2% brown coal) of electric energy in Poland is produced from coal (Grudziński, 2010). One of generally accessible, and still idle sources of renewable energy is the sun. Our planet receives 15 000 times of solar energy more than energy that we produce out of conventional sources. It is estimated that within the next 10 years, there will be a balance observed between the process of energy obtained in a conventional way and in the process of photovoltaic conversion (Jastrzębska, 2013). The Ministry of Economy has planned development of energy taking the advantage of photovoltaics till 2020 at the level of 2 MWp, but till 2030 at the level of 32 MWp (Hołub et al., 2010). It is worth emphasizing that renewable energy development will be mainly based on dispersed generation that allows reduction of losses resulting from energy transfer, which will significantly improve energy safety of the state and will reduce emission of greenhouse gases (Popczyk, 2011).

Generally, photovoltaic systems may be divided into (Jastrzębska, 2009; Jastrzębska, 2013; Forest and Simoes , 2006; Sarniak, 2009):

– autonomous (independent systems, comprising of a battery of photovoltaic panels, energy buffer – batteries, monitoring system and supervision of the system work, and DC/AC inverter – optionally);
– the ones cooperating with power network (system comprising a battery of photovoltaic panels and DC/AC inverter with capacity of direct cooperation with power network);
– hybrid (a combination of a photovoltaic generator with another system of energy production, e.g. wind power station).

A special type of autonomous system is a so called conjugated system. It comprises a battery of photovoltaic panels only, which is attached directly to a receiver (Jastrzębska, 2013). A photovoltaic hydrogen generator or installations for tap water heating may be included in this type of systems. This type of system is characterized by the simplicity of its construction, and much lower costs of production, when compared to systems with a buffer of electric energy. All types of the systems mentioned above can be used in households. It is estimated now that in Europe photovoltaic systems in households constitute 23% of photovoltaic systems in general, and their yearly increase is estimated at the level of 35% (Jastrzębska, 2013). Apart from being used to supply energy to typical household appliances, photovoltaic cells can also be used to supply energy to household means of transport (electric cars, single-track vehicles with electric drive) as well as vehicles used in a garden (battery-powered lawnmower, battery pump, etc.) (Carroll, 2003).

The advantage of photovoltaic systems used to supply energy to appliances in a household is that they are practically unattended contrary to biomass power generators, and they do not make noise, which is characteristic in case of wind power stations. Their disadvantage may be low efficiency (e.g. sillicon monocrystalline up to 24.7%, sillicon polycrystalline up to 20.3% (Panek, 2011), and instability of efficiency, for the perspective both of a day, and a year.

The aim of the paper is to evaluate exploitation characteristics of a system of tap water heating in a household supplied in energy from batteries of photovoltaic panels.

Characteristic of the research point and the course of measurements

In order to achieve exploitation characteristics there has been designed and made a prototype point of hot tap water heating, which was supplied by energy from photovoltaic cells (fig.1). The research point was installed in a household located in Zwierzewo (Ostróda province, Warmińsko- Mazurskie Voivodeship). The point is a classical conjugated system composed of 6 batteries of polycrystallic photovoltaic panels by DMEGC (DM235-P156-

60) and a heater installed in a hot water tank of 140 dm^3 capacity by Galmet. The tank was a part of the system exploited before.

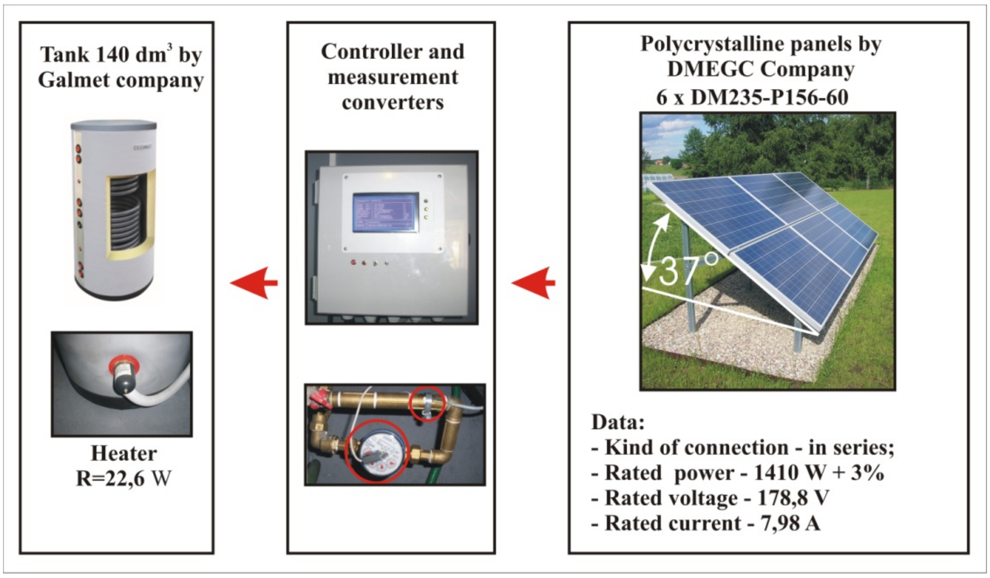

Figure 1. Picture of hot tap water system components in a household supplied by energy by means of photovoltaic panels

Resistance of the heater (22.6 Ω) was set in a way to obtain maximum energy efficiency of the batteries of photovoltaic panels. Panels were put in series connection and the following parameters were achieved: rated current of the value of 7.98 A, rated voltage of the value of 178.8 V, and rated power of the value of 1410 W. Battery efficiency was at the level of 14.5%. Panels were mounted on a static steel frame. They were directed to the south and the tilt angle value was 37º. It is the optimum position from the point of view of efficiency for the geographical location (53º42'25"N; 20º2'1"E). Panels tilt angle was calculated in „Photovoltaic Geographical Information System" calculator available at the website (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php). Recording of time courses of action of selected working parameters, as well as monitoring of the research point functioning was made by means of a controller designed and produced for the requirements of the research, which remained in cooperation with measurement converters (Figure 2). For practical use, in systems that do not require monitoring of the value of selected working parameters, instead of a controller, it is sufficient to mount a thermostat that prevents from heating tap water to a too high temperature. It is a much cheaper and practical solution. The cost of mounting a point with a thermostat was estimated at PLN 5 660, in case of purchasing brand new panels, or PLN 3 980, in case of purchasing the panels from the secondary market.

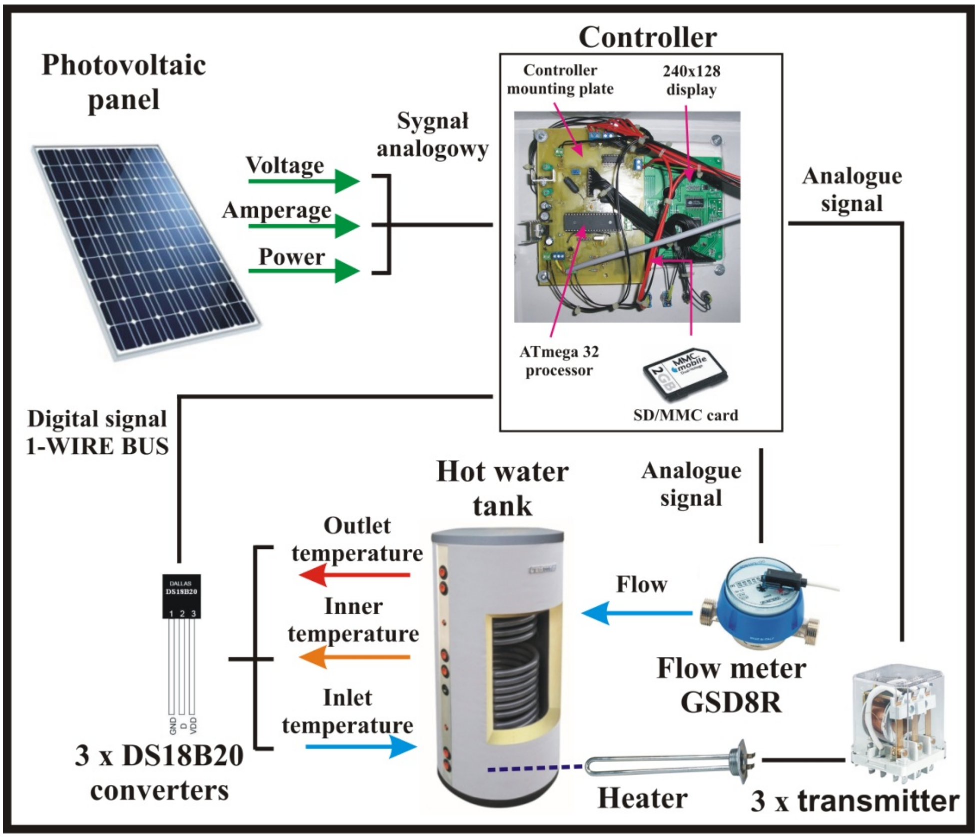

Figure 2. Scheme of monitoring system and supervision of tap water heating system

A designed controller was produced based on Atmega32 processor. It remained in co-operation with graphic display of 240x128 resolution. Memory card SD/MMC was used to record time courses of action of selected working parameters of the system. Data was recorded with 1 Hz frequency.

During the system functioning, the following working parameters were noted:
- voltage directly at the control clamp of photovoltaic panel of batteries;
- intensity directly at the control clamp of photovoltaic panel of batteries;
- power directly at the control clamp of photovoltaic panel of batteries;
- temperature at the intake pipe connector to the hot water tank (DS18B20 converter);
- temperature at the outlet pipe connector from the hot water tank (DS18B20 converter);
- temperature inside the tank of hot water (DS18B20 converter);
- flow of hot water (converter that cooperates with flow-meter GSD8R).

Applied converters cooperated with the processor using its analogue intakes data transfer buses 1-WIRE BUS. Through analogue intakes, the controller was able to operate three collectors of energy generated by a battery of photovoltaic panels. The presented system is an open one, and there is a possibility of its further development.

Observation of time course of action of selected functional parameters was carried out in the period preceding summer solstice (7:04 on 21st June 2013) and some days later, because of the most favourable relationship of the day versus the night. On these days it is possible to obtain highest capacity of the system because it is characterised by a possibility of generating energy, depending on the weather conditions and season of the year.

Analysis of the research results

In the given period, the lowest value of the working efficiency was observed on 14th June 2013 (during the day it was mostly cloudy), and the highest on 17th June 2013 (clear sky without clouds was observed from 10:00 a.m., and then after 5:00 p.m.). For those days, the observed results were in the extreme in the period that was object of the research, and the results relating to those days were subject of further analysis.

Figures 3 and 4 present time courses of action of generated power by the system in the period of two days that were characterised by different level of sunny weather.

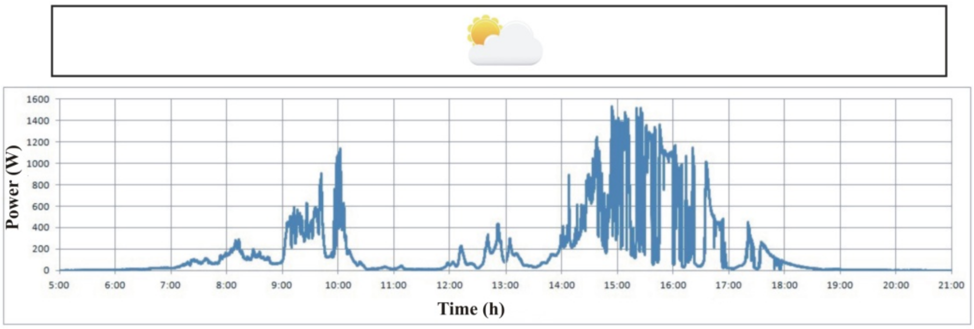

Figure 3. Time course of action of generated power by the system on 14th June 2013

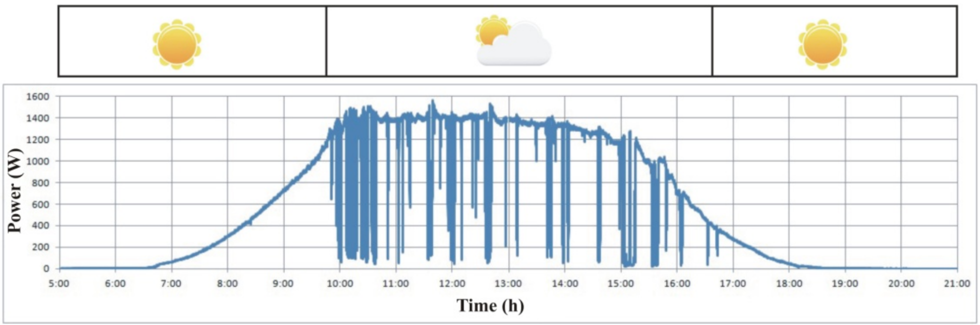

Figure 4. Time course of action of generated power by the system on 17th June 2013

Table 1 presents parameters that characterize work of tap water heating system on 14th and 17th June 2013.

Table 1
Parameters characterising work of tap water heating system

Characteristics of exploitation parameters	14th June 2013	17th June 2013
Average temperature of water at intake pipe connector to hot water tank (ºC)	14.85	14.82
Average temperature of water at outlet pipe connector from the hot water tank (ºC)	33.94	53.56
Minimum temperature of water in the tank (ºC)	31.8	42.19
Maximum temperature of water in the tank (ºC)	41.94	69.38
Water volume increase with temperature in the tank (ºC)	10.6	27.19
Consumption of hot water from the hot water tank (dm^3)	59	89
Average generated power (W)	180.59	565.22
Generated energy (kWh)	2.88	9.04
Usage indicator (%)*	12.76	40.07
Exploitation usage indicator (%)**	29.5	92.62

* – related to the energy that panels are able to produce in ideal conditions

** – related to the energy that panels are able to produce on a cloudless day for assumed tilt angle equal to 37° and given geographical location

Based on obtained results, it is possible to state that the battery of photovoltaic panels of total rated power 1,410W on a sunny day in June is able to produce a maximum 9.76 kWh of energy (amount assumed on the basis of analyzed power characteristics of 17th June 2013, with time of recording taken into account).

On 17th June 2013 the system generated 92.62% of energy that for a given configuration it was possible to obtain (this parameter defines also ratio of sunny weather during the day). On 14th June 2013, due to the fact it was cloudy, the amount of produced energy was three times lower than on 17th June. Such small amount of energy should be found insufficient in order to heat water (obtained energy was too low in order to heat realistic amount of water for a three-persons family to the temperature above 40ºC). Figures 3 and 4 allow observation of the dynamic decrease of power battery in photovoltaic panels, proportionally to the rate of cloudy weather. Within some seconds, generated power reaches the zero level, which makes it impossible to supply energy to majority of appliances in a household without the application of a system for buffering energy.

The presented system requires further research in order to define minimum capacity of hot water tank as an energy buffer and minimum number of panels comprising a battery, in order to secure required amount of hot tap water in summer season. In the present form, the system can be exploited as supplementary for tap water heating, in combination with conventional systems (e.g. provided in energy from power network).

Conclusions

1. The system of tap water heating presented in the paper is able to heat water itself on sunny summer days in order to heat water and fulfil realistic requirements of a three-persons family (on 17th June 2013 89 dm^3 were consumed from the tank, of the temperature from 42.19 to 69.38°C). On cloudy days, with applied solution, it can be used as a supplementary system of tap water heating when combined with conventional systems.
2. The presented system requires further research in order to define minimum capacity of hot water tank as energy buffer and minimum number of panels comprising a battery, in order to secure a required amount of hot tap water in summer season, according to requirements included in the Regulation by the Minister of Infrastructure of 14th June 2002, related to defining average norms of water consumption (Journals of Law 8/02 item70).
3. Direct energy supply of the heater in the hot water tank allows to reduce significantly the cost of materials necessary to make the system (configuration with a thermostat), the cost of which was estimated at PLN 5660, in case of purchasing brand new panels, or PLN 3980, in case of purchasing panels from the secondary market.
4. Systems of dispersed energy generation, based on photovoltaic cells are characterised by unattended exploitation and quiet functioning, they do not influence the environment in a negative way. However, defining the profitability of their application in the context of obtained efficiency requires further research in subsequent seasons of the year.

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ANALIZA WYKORZYSTANIA OGNIW FOTOWOLTAICZNYCH W GOSPODARSTWIE DOMOWYM

Streszczenie. Przedstawiono zagadnienie wykorzystania ogniw fotowoltaicznych do ogrzewania ciepłej wody użytkowej (CWU) w gospodarstwie domowym. Zbudowano stanowisko badawcze posadowione na domu jednorodzinnym usytuowanym w środowisku wiejskim. Celem badań było uzyskanie maksymalnych charakterystyk wydajnościowych układu do podgrzewania CWU opartego na ogniwach fotowoltaicznych. Przeprowadzono je w okresie przesilenia letniego, ze względu na najkorzystniejszy pod względem wydajności stosunek czasu dnia do nocy. Uzyskane z badań wyniki umożliwiły pozyskanie wielu charakterystyk eksploatacyjnych opisujących system. Zamieszczono przykładowe przebiegi czasowe generowanej mocy oraz wybrane parametry robocze. Wyznaczono maksymalną wydajność energetyczną układu. Dalsze badania powinny umożliwić ustalenie minimalnej pojemności zbiornika CWU jako bufora energii i minimalnej ilości paneli wchodzących w skład baterii do podgrzewania wody, by spełnić wymagania zawarte w Rozporządzeniu Ministra Infrastruktury z dnia 14.01.2002, w sprawie określenia przeciętnych norm zużycia wody (Dz. U. 8/02 poz. 70).

Słowa kluczowe: fotowoltaika, energia odnawialna, generacja rozproszona