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RESEARCH OF ELECTRICAL AND PHYSICAL CHARACTERISTICS OF THE SOLAR PANEL ON THE BASIS OF COGENERATION PHOTOELECTRIC MODULES

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Introduction. In order to save energy sources, there has recently been a significant increase in an interest to develop electric vehicle chargers based on alternative energy sources. The most popular source of energy for their implementation is solar batteries [1].

Countries of Europe, China and India have announced that they will refuse to sell cars with internal combustion engines in 10-25 years, moreover, the carmakers themselves began to focus on the production of hybrids and electric vehicles. Plans for switching to electric drives have been announced by BMW, Daimler, Volkswagen Group and others. It is expected that the number of electric vehicles will cross the mark of 5 million by the end of this year. The Razumkov Center predicts that every fourth car in Ukraine will be electric by 2035 [2].

As of January 1, 2019, there were 1,179 charging stations for electric vehicles in Ukraine. The infrastructure of charging stations in Ukraine is made up of either stations specializing only in recharging of electric vehicles, known as gas stations, or off-line chargers at restaurants, hotels, and other institutions. At the same time, it can be noted that there is an acute shortage of fast charging stations in Ukraine. They are ten times less than usual stations [3].

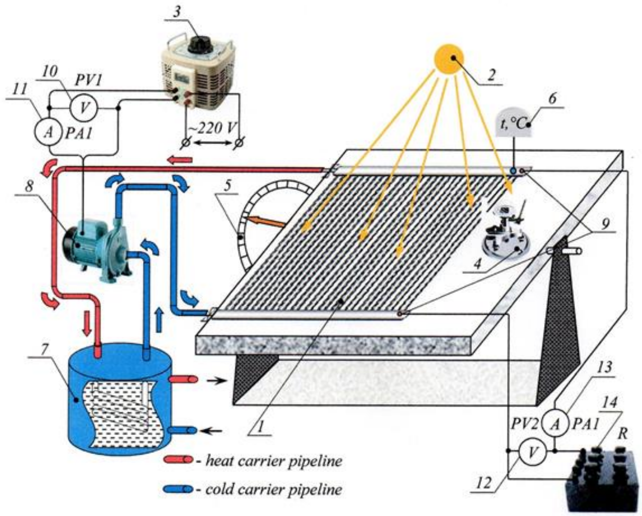
The possibility of creation of local energy networks for charging of electric vehicle batteries at existing stationary gas stations based on solar photovoltaic panels (SPVP) is grounded in the work [4]. To increase the efficiency of the SPVP, it is proposed to use cogeneration photovoltaic modules (CPVM) instead of flat solar panels. This will open up the possibility of creation of a hybrid SPVP for the simultaneous generation of electrical and thermal energy.

The purpose of the work is to obtain electrical and physical characteristics of a hybrid SPVP on the basis of cylindrical cogeneration (hybrid) CPVM, which are cooled, to charge batteries of electric vehicles.

Basic research materials. Electrical and physical characteristics of the SPVP are the most important parameters, estimating which one can make a reasonable choice about the prospect of using the panel to create a solar power plant with the necessary value of the output electric power [5]. These parameters include: short-circuit current, idle voltage, efficiency, etc. To estimate these parameters, the volt-ampere characteristics (VAC) of the SPVP are constructed in the work. To investigate and obtain the VAC of the hybrid SPVP, an experimental assembly was developed, the scheme of which is shown in Fig. 1.

1. Description of the experimental assembly.

The basis of the experimental assembly is made up of a table with a system of an angle inclination change of a board (5), on which the hybrid SPVP (1) under research is fixed. The design scheme of the hybrid SPVP based on cylindrical cogeneration CPVMs is shown in Fig. 2. To measure the intensity of light energy, a thermoelectric M-80M pyranometer (4) with a GSA-1 galvanometer, which is attached on the rotatory board of the assembly (not shown in Fig. 1), are used. When the board is turned, the angle of radiation of the SPVP and the pyranometer changes at the same time. To measure the heating temperature of the photovoltaic converter (PVC) of CPVM, a thermoconverter with a resistance (6) of the TERA-TSM-2-8-100M-B-3-2000-ME (-50… 180) type, which is fixed on the surface of the PVC, is used. A closed cooling system is used to investigate the characteristics of the PVC dependent on its heating temperature. The cooling system consists of pipelines, a single-phase circulating pump (8) of the Aquatica 775224 type with a capacity of 1.1 kW and a supply of 220 l/min and a heat accumulator (7) of 200 l volume. The PVC temperature of the hybrid CPVM is controlled by the supply of a coolant by adjusting the speed of the rotation of the pump (8), which varies with the amount of voltage applied to the pump.



1 – SPVP; 2 – Sun; 3 – LAVT; 4 – pyranometer; 5 – system of angle inclination change of SPVP; 6 – temperature sensor; 7 – heat accumulator of a cooling system; 8 – circulation pump; 9 – output terminals; 10, 12 – voltmeters; 11, 13 – ammeter; 14 – load

Fig. 1. **Scheme of the experimental assembly for the research of the hybrid SPVP on the basis of cylindrical cogeneration CPVM**

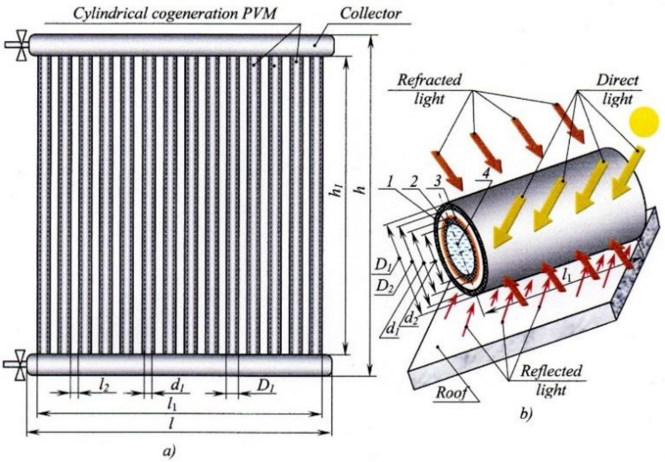
Adjustment of the pump supply voltage is carried out by a laboratory autotransformer (3) of alternating voltage (LAVT) of TDGC2-2K type with a rated power of 2 kW and a rated current of 8 A. Antifreeze is used as the coolant of the cooling system. Normal tap water is fed into the thermal accumulator.

In order to control the load on the SPVP, a resistance store P33 (14) is connected to the output terminals (9). DT830 (832) multimeters are used to measure the supply voltage of the pump (8) and the current consumed by it, as well as the output voltage of the SPVP and the load current.

In the hybrid SPVP, fourteen CPVM are used, the PVC of which are connected in parallel, so the total current of the SPVC is equal to:

$$I_{CPVP} = n \cdot I_{CPVM} = n \cdot I_{PVC}, \quad (1)$$

where:



a) hybrid SPVP; b) cylindrical cogeneration PVM
1 – outer tube; 2 – inner tube; 3 – PVC; 4 – coolant

Fig. 2. **Design scheme of a hybrid SPVP and an absorption of solar rays by cogeneration PVM**

n = 14 – quantity of CPVM in SPVP.

The structure of the CPVM and its geometric dimensions are shown in Fig. 2, given in [6].

2. Exploration of the power density of solar radiation.

The hybrid SPVP study was conducted on April 8, 2020 in Melitopol, Zaporizhzhya Oblast, in one of the private dwellings, which has the following geographical coordinates: 46°50' north latitude and 35°22' east longitude. The length of a day is 13 hours 14 minutes, sunrise - 6 hours 3 minutes, sunset - 19 hours 17 minutes. The UV index is moderate.

To obtain the maximum power from the SPVP, it is necessary to orient its plane to the Sun. To absorb the largest amount of solar energy, the SPVP plane must always be perpendicular to the sun's rays [7]. We install the experimental assembly on a horizontal surface, in a place where a shadow does not drop on the SPVP during the light part of the day, at an angle of 46°50' and obtain the maximum specific power of solar radiation, measuring it every 2 hours. The results of the experiment are shown in Fig. 3,a.

The power density distribution p, W/m^2, of solar radiation from the operating time t, s, during the light time of a day τ, s, obeys the sinusoidal law, and can be determined by the expression [8].

$$p(t) = p_{max}\, sin\left(\frac{\pi t}{\tau}\right) \quad (2)$$

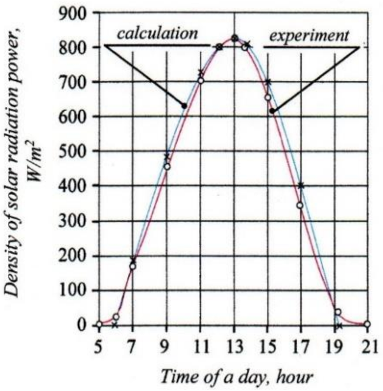
The maximum power density p_{max} is 825 W/m^2 at 13:00 p.m. (Fig. 3,a). In Fig. 3,a the calculated dependence obtained by expression (2) is given. We see a slight error of experiment and calculation, so expression (2) can be used to calculate.

Further, at maximum power density p_{max} (13:00 p.m.), the dependence of the solar radiation power density p on the SPVP angle of inclination β (Fig. 3,b) was investigated. As we can see, the maximum power density p_{max} will be at β = 46°. Therefore, to obtain the maximum power from the SPVP, it must be set at an angle equal to the latitude of the area where the solar station will operate.

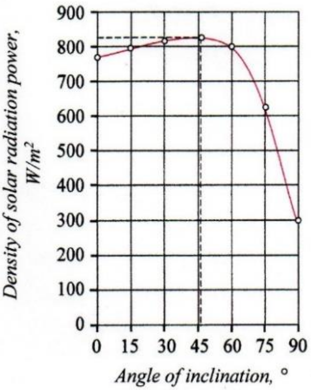
3. VAC of the SPVP.

The VAC of the SPVP were investigated at a constant CPVM temperature, which was maintained at 50°C, by controlling the supply of the coolant by the pump. The temperature value of 50°C is grounded in [6]. SPVPs VAC were measured from the mode close to the open circuit (high load resistance) - idle mode. The measurement of voltage and current was performed by multimeters 12, 13 (Fig. 1). The load resistance was further reduced so that the output voltage of the SPVP was 36 V and further with a discreteness of 6 V. It was mandatory to determine the point at which the SPVP would have the maximum power P_{max}, which would correspond to the maximum current I_{max} and the voltage U_{max}. The experiments were performed at a fixed maximum specific power density of p_{max} at 7:00 a.m. (p_{max} = 170 W/m^2), 9:00 a.m. (p_{max} = 450 W/m^2), 11:00 a.m. (p_{max} = 700 W/m^2) and 13:00 p.m. (p_{max} = 825 W/m^2). P_{SPVP} power was determined by the expression:

$$P_{SPVP} = U_{SPVP} I_{SPVP} \quad (3)$$



(a)



(b)

Fig. 3. **Dependences of solar radiation density on time of a day (a) and angle of inclination of SPVP (b)**

The VAC and the SPVP power characteristics obtained experimentally are shown in Fig. 4. The maximum output power P_{max} at a specific solar radiation power density of 825 W/m^2 is 381 W at the output voltage U_{max} = 34 V and the output current I_{max} = 11 A.

Further, we need to determine the output specific maximum power of the SPVP per 1 m^2 of its area:

$$P_{SPVP\,spe} = \frac{P_{SPVP}}{S_{SPVP}}, \qquad (4)$$

where: S_{SPVP} - area of SPVP.

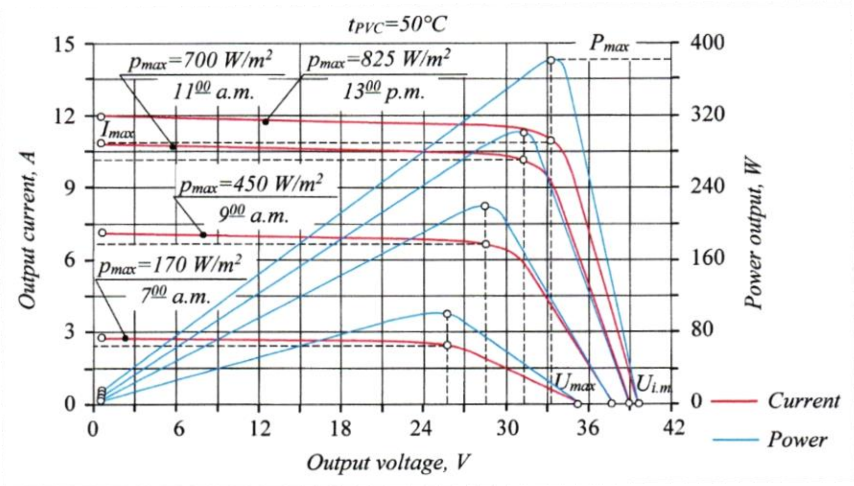


Fig. 4. **Volt-Ampere characteristics and characteristics of SPVP power**

The overall dimensions of the developed SPVP are: h = 1.7 m, l = 1 m. For the production of CPVM, tubes made of borosilicate glass of a T-300C brand with the following parameters were used: outer tube - D_1 = 50 mm, wall thickness Δ = 2.5 mm, D_2 = 45 mm; inner tube - d_1 = 30 mm, wall thickness Δ = 2.5 mm, d_2 = 25 mm; tube length h_1 = 1500 mm. Thus, the $P_{SPVP\,spe}$ = 381/(1.7·1) = 224 W/m^2.

We compare the developed hybrid SPVP, which has the parameters mentioned above, with the JA Solar JAM60S09-325PR solar panel manufactured by JA Solar and widely used for the construction of solar power plants worldwide [9]. It has the following basic technical characteristics: P_{max} = 325 W, $U_{i.m.}$ = 41.04 V, $I_{s.c.}$ = 10.25 A, U_{max} = 33.4 V, I_{max} = 9.72 A, overall dimensions 1657 mm × 996 mm × 35 mm.

The area of the solar panel JA Solar is equal to S_{SP} = 1,65 m^2, then the output specific maximum power of it is P_{SPspe} = 325/1.65 = 197 W/m^2. Thus, the efficiency of the hybrid SPVP developed by us compared to the solar panel JA Solar JAM60S09-325PR is equal to:

$$k_{eff} = \left(1 - \frac{P_{SP\,spe}}{P_{SPVP\,spe}}\right)100\% = \left(1 - \frac{197}{224}\right)100\% = 12{,}1\% \cdot$$

Conclusion.

1. An experimental assembly for the research of the electrical and physical characteristics of a hybrid SPVP based on cylindrical cogeneration SPVM, which allow to stabilize the temperature of the PVC SPVM during the experiments and to increase the reliability of the obtained electrical and physical characteristics of the SPVP, was developed.
2. The dependence of the solar radiation power density on the time of a day and the angle of inclination of the SPVP, which have a small error, which makes it possible to use a mathematical model (2) to calculate this dependence, were obtained by experimental and calculated ways.
3. The VAC and the characteristics of the output power of the developed hybrid PVC were experimentally investigated. It was established that at a maximum specific power density of 825 W/m^2, the hybrid SPVP has an output maximum power of 381 W at a maximum output voltage of U_{max} = 34 V and an output current of I_{max} = 11 A.
4. Comparative analysis of the developed hybrid SPVP with JA Solar JAM60S09-325PR solar panel, which has the best performance among those solar panels produced by the industry, were conducted. Moreover, it was determined that the efficiency of the developed SPVP is better by 12.1%.

References:

[1] Павлов, В. Б., Будько, В. І., Кириленко, В. М., Будько, М. О. & Кириленко, К. В. (2019). Особливості роботи автономних зарядних станцій електромобілів з використанням фотоелектричних установок та буферних акумуляторів енергії. *Праці ІЕД НАН України*, (53), 117-125. https://doi.org/10.15407/publishing2019. 53.117.

[2] Электромобиль приближает конец нефтяной эры. (2019). Вилучено із http://savenergy.info/page/electric-car-near-end-oil-era/

[3] Галько, С. В., Жарков, В. Я. & Жарков, А. В. (2019). *Технології та засоби перетворення відновлюваних джерел енергії для приватних домогосподарств*. Мелітополь: Люкс. ISBN 978-617-7218-62-2.

[4] Галько, С. В. (2019). Використання когенераційних фотоелектричних модулів для зарядки електромобілів. *Праці Таврійського державного агротехнологічного університету*, 19(3), 130-141. https://doi.org/10.31388 /2078 -0877-19-3-130-141.

[5] Какурина, Н. А., Какурин, Ю. Б., Курсай, Д. Е. & Осипов, Н. А. (2016) Исследование электрофизических характеристик солнечной панели с помощью компьютеризированного измерительного стенда. *Инженерный вестник Дона*, (3). Вилучено із http:idvon.ru/uploads/article/pdf/IVD_37_kakurin_kakurina.pdf_ e3a16aeaf8.pdf.

[6] Галько, С. В. Експериментальне дослідження і визначення параметрів когенераційного фотоелектричного модуля для гібридних сонячних електростанцій. *Традиційні та інноваційні підходи до наукових досліджень: матеріали міжнародної наукової конференції*. (Т. 1, с. 83-90). 10 квітня, 2020, Луцьк, Україна: МЦНД. https://doi.org/10.36074/10.04.2020.v1.10.

[7] Кашкаров, А. П. (2011). *Ветрогенераторы, солнечные батареи и другие полезные конструкции*. Москва: ДМК Пресс.

[8] Марахтанов, М. К., Духопельников, Д. В., Ивахненко, С. Г. & Крылов, В. И. (2014) Электрогидравлический баланс солнечного теплоаккумулятора с автономным электроснабжением. *Наука и образование*, (ФС77-48211), 332-342. https://doi.org/10.7463/0214.0697540.

[9] *Солнечная панель JA Solar JAM60S09-325PR*. (2020). Вилучено із http://goingsolar.com.ua.