Hybrid photovoltaic modules: comparison of lab and field research.

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Operating modes of a hybrid photovoltaic module based on A_3B_5 and Si-HJT heterostructure solar cells have been investigated. An increase in the concentrator module power generation due to the planar circuit under a changing balance between direct and total solar radiation was estimated. An increase in the planar circuit power generation in the single-facial and bifacial modes was determined: a more than double increase in the circuit photocurrent was fixed. Taking into account the temperature correction, a similarity between the laboratory measurements of photovoltaic characteristics of the solar module circuits and field research data has been shown for comparable irradiances.

Keywords: hybrid concentrator-planar photovoltaic module, multi-junction solar cell, Si-HJT planar photovoltaic converter, diffuse radiation.

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A significant progress in developing conceptual solutions for hybrid (concentrator-planar) solar modules [1] is caused not only by the necessity of increasing the total energy efficiency of photovoltaic installations comprising highly efficient concentrator modules and tracking systems, but also by reduction in the amplitude of power-output fluctuations in the case of either the combined („direct + diffuse") character of incoming radiation or predomination of only diffuse component.

A characteristic feature of hybrid photovoltaic modules (HPM) is the presence of two electrically separated but optically coupled circuits, the concentrator and planar ones, built, respectively, on the basis of highly efficient heterostructure A_3V_5 photoconverters [2] and Si photoconverters, such as c-Si, HJT (heterojunction technology), PERC (passivated emitter rear cell), and IBC (interdigitated back contact) [3]. To assess the total power effect (an increase in the total HPM power output with respect to the same characteristic of its components, i.e. the concentrator and planar circuits), the characteristics were considered independently.

The paper presents the results of laboratory and field studies of HPM comprising two photovoltaic cells based on the bifacial Si-HJT structures (planar circuit) and 32 concentrator cells (40 × 40 mm each) combined in the 4 × 8 format [4].

Under natural conditions, the operating efficiency of HPM circuits was assessed by long-term monitoring within a solar photovoltaic plant equipped with a tracking system [5]. The monitoring system hardware allowed measuring the level of solar radiation (total, direct, diffuse, albedo) and temperatures of ambient air and photovoltaic converters. Long-term HPM operation in the maximum power extraction (electrical „cooling") mode was ensured; thereat, current-voltage characteristics were regularly measured, which increased the accuracy of the obtained estimates of photovoltaic parameters and power efficiency. Concurrently, the accuracy of the system pointing in the „Sun" direction was monitored [6]. Data on the efficiency of module circuits were acquired: relatively to direct solar radiation components for the concentrator module, relatively to the diffuse and albedo radiation for the planar module. Operating modes of the hybrid module under the clear-sky and different partly cloudy conditions (Fig. 1), as well as under the haze and completely cloudy conditions, were considered.

Under clear sky, the increment in electric power generation by the planar circuit (efficiency of 16%, AM1.5G, 100–200 W/m^2, power output of 32 W/m^2) was about 5–10% of the power output of the concentrator circuit (efficiency of 32%, AM1. 5D, 800–1000 W/m^2, power output of 250–320 W/m^2), while under the partly cloudy conditions with the diffuse-radiation share of more than 60% (efficiency of 18%, AM1.5G, 200–400 W/m^2, power output of 36–7 2 ,W/m^2) the increment appeared to be comparable to or exceeding the power output of the concentrator circuit. An increase in the planar circuit power output in the single-facial and bifacial modes was evaluated, and a more than double increase in the circuit photocurrent was fixed.

During the 2022 season (from June 17 to September 7), monitoring of the total power output of individual cascades was carried out at the site located in St. Petersburg (Fig. 2). The measurements showed that power generated by the concentrator circuit varies strongly (sharply) depending on the incoming direct radiation, while for the planar circuit such jumps are unusual since in this case the level of the diffuse solar radiation component varies more gradually.

In the laboratory conditions, considerable attention was paid to modeling the parameters of solar radiation for its subsequent conversion by the HPM photovoltaic circuits.

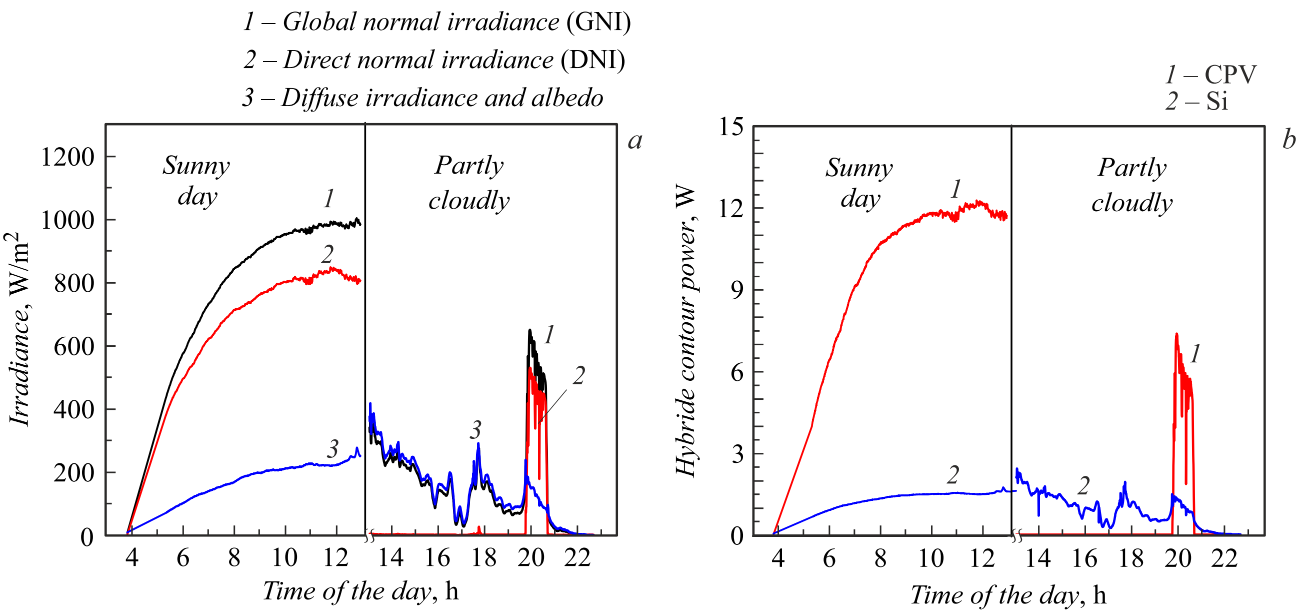

Figure 1. Results of monitoring the HPM power output. The solar radiation arrival to the tracking surface (a) and instantaneous electric powers generated by the concentrator (CPV) and planar (Si) circuits (b) on characteristic days: clear days (left panels), partly cloudy days (right panels).

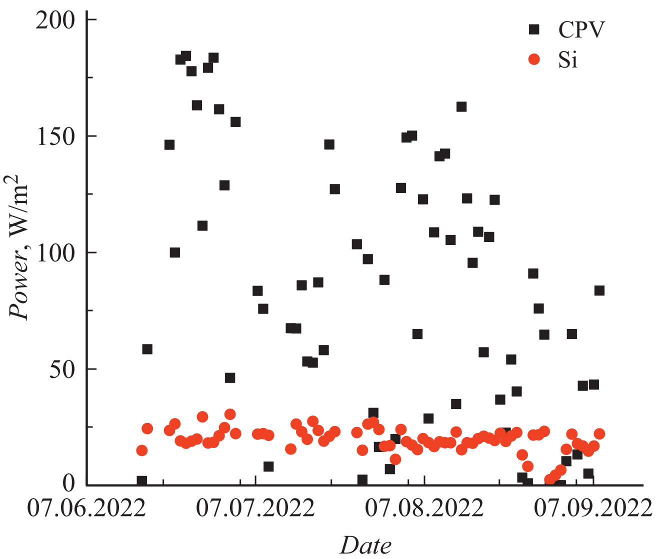

Figure 2. Results of monitoring the HPM power output: absolute values of powers generated by the concentrator and planar circuits throughout the day.

To reproduce the parameters of direct solar radiation (1000 W/m^2, AM1.5D, angular divergence of 32 arcmin), a simulator [7] was used whose functionality was modernized in accordance with specificity of the double-circuit design of the research object. To simulate the diffuse component, specially selected screens with different levels of scattering and transparency were set into the light flux. Based on the data obtained under natural conditions, irradiance of HPM circuits was simulated. The concentrator circuit was tested under illumination with a collimated flow of 500–1000 W/m^2 (AM1.5D). In the long-term test mode, temperature coefficients of the open-circuit voltage were assessed and appeared to be 0.15%/°C for the concentrator circuit against 0.29%/°C for the planar one. Taking into account the temperature correction, a good agreement was shown between the concentrator circuit measurements (Fig. 3, a) and field research data obtained at comparable illuminations. As for the planar circuit, the data compliance was observed in the „single-facial“ case (Fig. 3, b).

Simulation of the planar circuit operating conditions for the „diffuse radiation + albedo“ irradiation mode requires further development of experimental techniques and laboratory instruments.

Operating modes of the hybrid concentrator-planar module under the clear-sky and different partly-cloudy conditions have been studied. The increment in electrical power generated by the planar circuit under different weather conditions was estimated. This increment was shown to be comparable to or exceeding the concentrator circuit output under the partly-cloudy conditions. Current-voltage characteristics of the concentrator and planar circuits were measured under natural conditions and with the modernized solar radiation simulator under comparable illuminations; the results were shown to be consistent.

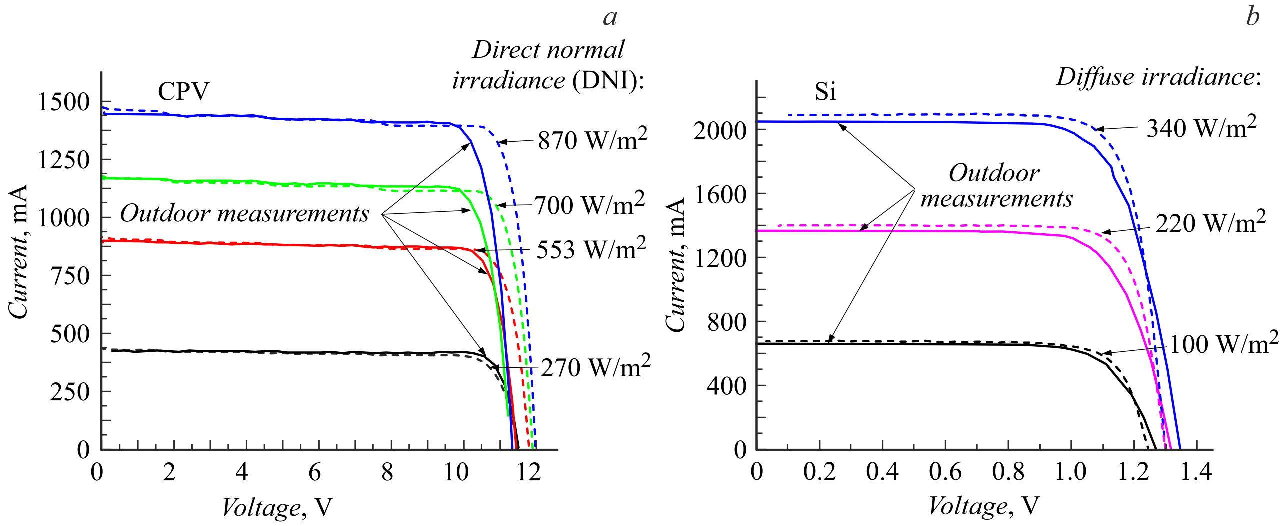

Figure 3. Current-voltage characteristics of the concentrator (*a*) and planar (*b*) circuits measured under natural conditions and at the modernized solar radiation simulator under comparable illuminations. The concentrator circuit was illuminated by direct radiation (direct normal irradiation, DNI), the planar circuit was illuminated by diffuse radiation (in the single-facial mode).

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Conflict of interests

The authors declare that they have no conflict of interests.

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