Method for controlling the ratio of the direct and diffuse components of solar radiation when measuring photovoltaic characteristics of a hybrid module

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The article discusses the development of a technique that allows for regulating the direct and diffuse light flux components in order to control the hybrid module power output under laboratory conditions. Under natural conditions, an increase in the diffuse radiation proportion in the total hybrid-module flux leads to blurring of the light spot and decrease in the integral illuminance of the concentrator element. This results in the illuminance redistribution between the hybrid-module concentrator and planar circuits. Reproducing the radiation with a controllable „direct/diffuse"balance enables investigation of the hybrid module characteristics under controllable conditions.

Keywords: hybrid module, direct and diffuse radiation, energy illumination distribution, luminous flux with controllable parameters.

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The current stage of the progress in solar-photovoltaic power engineering is associated with the so-called „combined" (or „hybrid") concepts [1–3] combining the advantages of highly efficient planar-silicon and concentrator-multijunction A^3B^5 [4] solar cells whose efficiency exceeds 25 and 42%, respectively [5].

The double-circuit „concentrator-planar" system ensures smoothing of power-output fluctuations that are caused mainly by changes in weather conditions, which affect the balance of direct and diffuse radiation in the incoming solar radiation flux [6]. Planar circuits of the combined modules are less sensitive to those changes than the concentrator circuits, their efficiency varies only slightly. Under the conditions when exclusively direct radiation predominates, the concentrator modules exhibit almost twice higher efficiency and power output.

Under natural conditions, operation of photovoltaic modules depends on many factors, e. g. the solar radiation intensity, proportions of direct and diffuse radiation, air temperature, humidity, wind speed, etc. Having obtained data from long-term field tests, it is possible to estimate the effect of these factors on the power output of photovoltaic modules [7]. However, even with data available, reproduction of life-like conditions in laboratories is indeed a challenge. Even availability of special techniques and devices allowing for creation of life-like conditions may still appear to be insufficient; this stimulates development of new measurement techniques needing appropriate equipment.

The goal of this study was to develop a method for monitoring and reproducing the direct and diffuse components of radiation under laboratory conditions for the purpose of measuring the hybrid module photovoltaic characteristics.

In testing under natural conditions, when the fraction of diffuse radiation in the total light flux was increasing, blurring (size increase) of the focal spot formed by the concentrator was observed simultaneously with decreasing integral irradiance of the concentrator element. Under laboratory conditions, when solar radiation is modeled with simulators, control and monitoring of this blurring dynamics will provide information on the correctness of reproducing the light flux parameters in terms of the ratio between the direct and diffuse components and angular divergence of radiation.

The paper considers an optoelectronic device (Fig. 1, a) whose design and functionality are consistent with those of the „lens–hybrid module element" elementary cell; the device enables recording the profile of irradiance distribution in the lens concentrator focal plane, namely, controlling the transition from the mode of arrival of only the direct component of solar radiation (when all the radiation is concentrated on the multijunction solar cell) to the mode of arrival of only the diffuse component (when the focal spot is blurred). The device comprises:

— a radiation concentrator of the „Fresnel lens" type [8,9] (similar to that used in the hybrid-module concentrator circuit) having size of 6×6 cm, mean concentration ratio of 400, and maximal one of 2500;

— a translucent circular screen 8 cm in diameter to be instaled at the focal distance from the Fresnel lens (in the plane where the concentrator solar cell is assumed to be located);

— a camera installed behind the screen and displaying the light spot image on the screen.

The device operating procedure consists in recording the light spot with a camera and, after that, analyzing (profiling)

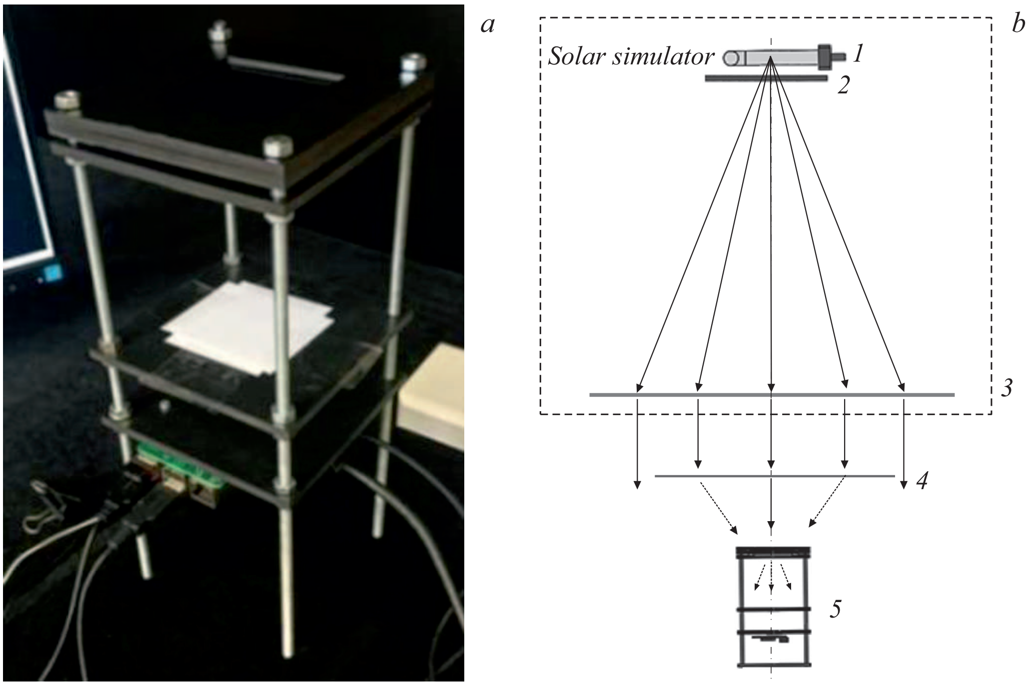

Figure 1. The device appearance (*a*) and optical scheme (*b*). *1* — radiation source (xenon lamp), *2* — aperture with a filter, *3* — collimated flux conditioner for simulating the direct solar radiation component, *4* — diffuser for simulating the diffuse solar radiation component, *5* — optoelectronic measuring device.

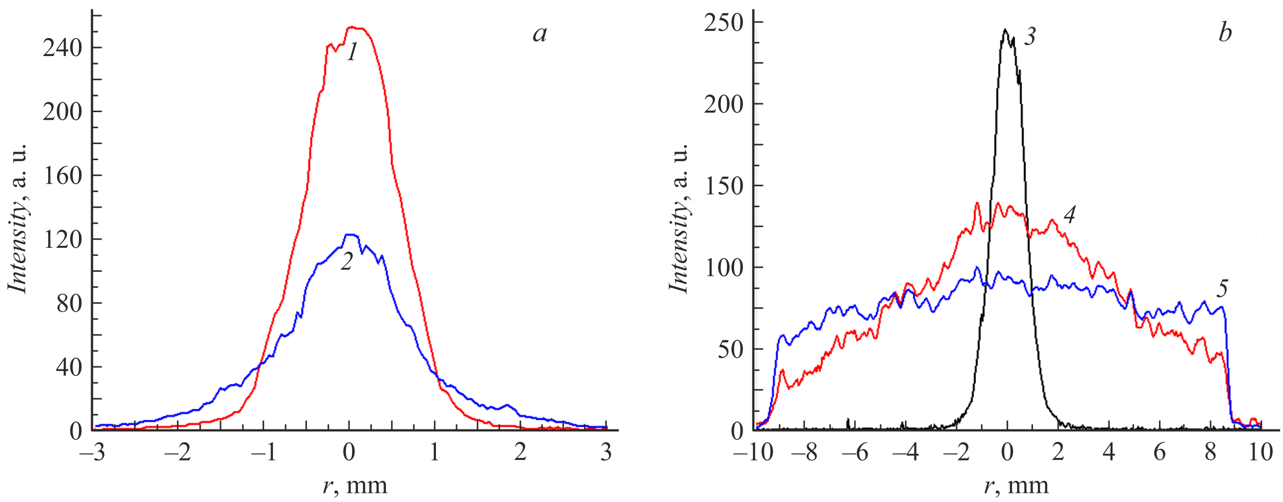

Figure 2. Distributions of energy illumination within the light (focal) spot *r* in radius measured under natural (*a*) and laboratory (*b*) conditions. Dependences *1* and *2* were obtained under clear and cloudy weather, respectively, dependence *3* was obtained using a solar radiation simulator, *4* and *5* were obtained using a solar radiation simulator with single-layer and double-layer scattering screens, respectively.

the intensity of the screen surface glow. The camera lens transfers (scales) the image to the photodetection matrix which provides, at the selected form factor, the resolution of 156 pixels per square millimeter of the screen, thus making possible a sufficient assessment of the intensity distribution within the light spot. Notice that this device is capable of operating under both the continuous and flash illumination.

Tests carried out under natural conditions showed that there is a relationship between the distribution of the light spot intensity and readings of the sensors (pyranometer and actinometer). When the fraction of scattered radiation is minimal, a bright spot is observed in the device lens focal plane. The subsequent redistribution of proportions of the direct and diffuse radiation components with simultaneous reduction in the total illuminance results in a decrease in the spot brightness and increase in its diameter.

Under laboratory conditions, the direct and diffuse components of radiation are reproduced by using the solar

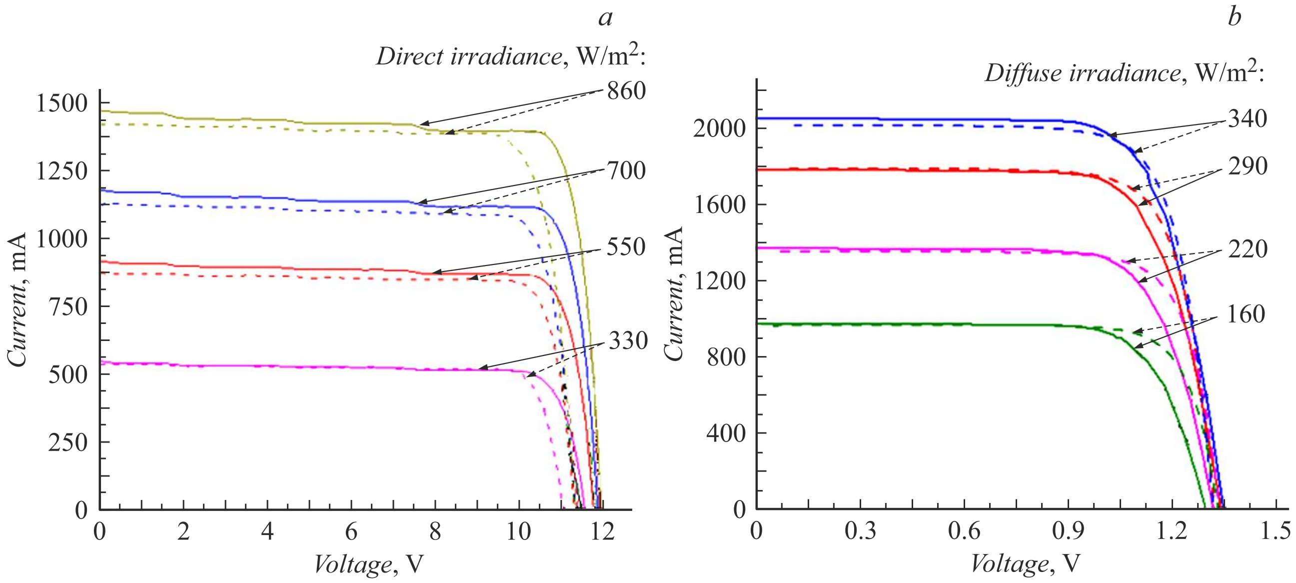

Figure 3. Current-voltage characteristics obtained under natural (dotted line) and laboratory (solid lines) conditions at different illuminance levels for the concentrator (*a*) and planar (*b*) circuits of the hybrid module.

radiation simulator; the diffuse radiation was obtained using scattering screens (Fig. 1, *b*). Energy illumination was regulated by varying the power source voltage of the simulator flash lamp.

When the diffuse radiation fraction in the total luminous flux increases, intensity distributions measured by the optoelectronic device under natural (Fig. 2, *a*) and laboratory (Fig. 2, *b*) conditions are of a similar character: the distribution recorded with the camera becomes more uniform.

Current-voltage characteristics obtained in the field and laboratory tests for the concentrator (Fig. 3, *a*) and planar (Fig. 3, *b*) circuits are almost identical except for the open-circuit voltage, which was explained by different temperature conditions of the tests.

The developed experimental devices (scattering screens for the simulator of direct solar radiation and optoelectronic device for measuring the irradiance profile in the concentrator focal spot) enabled realization of the technique of controllable variation of the ratio between the direct and diffuse light flux components. The developed technique allowed characterization of the hybrid modules under laboratory conditions by independently varying light fluxes to the concentrator and planar photovoltaic circuits.

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Conflict of interests

The authors declare that they have no conflict of interests.

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