Solar Simulator For Characterization Of The Large-Area HCPV Modules

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We report the results on design, manufacturing and test measurements of the solar simulator for high concentration PV systems with aperture area as large as 0.5 x 1.0 m^2. For correct HCPV module characterization, the light source must have an angular divergence similar to that of the sun (± 0.27º), and the optical image like the sun disc. In the developed simulator, two illumination sources are used in pair with two collimating Fresnel lenses of a silicone-on-glass structure. To eliminate the effect of the chromatic aberration and the non-uniform illumination in the peripheral zones of the measurement plane, the focal distance of each 0.5x0.5 m^2 lens was chosen to be as long as 2 m. Square lenses are placed firmly by sides one to another. In turn, each illumination source consists of two tube-like flash lamps and a screen with a hole 20 mm in diameter. Behind each of four lamp segments, a continuously operating LED is situated allowing for optical alignment of a tested concentrator system before flash illumination. Compact vertical arrangement of the optical elements ensures a footprint approximately of the size of the collimating lenses. I-V measurements are carried out during 1 millisecond– a period of a flat part of the light pulse. The results of the comparative I-V measurements in solar concentrator modules– outdoors and indoors with the help of the developed solar simulator– are presented as well.

Keywords: Concentrator modules, Indoor testing, Multijunction cells, Fresnel lenses.
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INTRODUCTION

Commercialization of the concentration PV systems needs for a tool to characterize the electrical and optical performance of the concentrator modules in the production line. At the PV Lab of the Ioffe Institute, a number of pulsed solar simulators have been developed for different applications [1-5]. Among them was a solar tester for characterization of the concentrator modules with the aperture area of 0.5x0.5 m^2 simulating the irradiance level, spectral distribution and light beam divergence similar to those of the sun [2, 3]. An approach to such a solar simulator design consisted in the use of a large-area Fresnel lens as a light collimating element placed in front of a flash lamp screened in turn by a light-limiting hole. The diameter d of this hole must be equal to 1/100 of the lens focal distance F (in above design F=780 mm and d=8 mm), so that the diameter of a tube-like body of a Xenon lamp fitted correctly to the hole diameter. I-V recording was carried out during 1 ms of one light pulse where light intensity kept practically constant. This simulator was used for characterization of the large aperture area concentrator modules based on one-junction AlGaAs/GaAs cells [2] and much smaller in size modules with triple-junction cells [3]. Disadvantage of the mentioned above design had been revealed at measurements of the larger in size concentrator modules equipped with triple-junction cells more sensitive to the chromatic aberrations in the illumination system.

Meanwhile a solar simulating system based on reflective optics (i.e. free of the chromatic aberrations) had been developed at IES-UPM [6, 7] and improved with respect to the measurement procedure at Fraunhofer ISE [8]. Unfortunately, this system, which includes a 2-m in diameter and 6-m in focal distance parabolic mirror, requires a big space for the module tests arrangement.

In the present paper, we report the results on design, manufacture and test measurements of the solar simulator on the basis of two 0.5x0.5 m^2 Fresnel lenses with the eliminated effect of the chromatic aberration and reduced absorption in the near infra-red part of the light spectrum. Compact vertical arrangement of the optical elements ensured a footprint approximately of the size of the light collimating lenses. The simulator validity has been demonstrated by comparative measurements (under sun illumination and with the help of the solar simulator) of the planned for production 0.5x1 m^2 concentrator modules based on InGaP/GaAs/Ge solar cells and silicone-on-glass Fresnel lens panels.

SIMULATOR OPTICAL DESIGN

For a correct HCPV module characterization, the light source must have an angular divergence similar to that of the sun (± 0.27º), and the optical image like the sun disc. In the developed simulator, two illumination sources are used in pair with two collimating Fresnel lenses (see Figure 1). To eliminate effect of the chromatic aberration and non-uniform illumination in the peripheral zones of the measurement plane, the focal distance F of each 0.5x0.5 m^2 lens was chosen to be as long as 2 m. Square lenses are placed firmly by sides one to another. Reduced absorption in the near infra-red light spectrum was ensured owing to fabrication of lenses by the silicone-on-glass technology [5]. In this case, the lens body consists mainly of highly transparent silicate glass, and polymer material (silicone) responsible for absorption is only microprisms in the Fresnel profile.

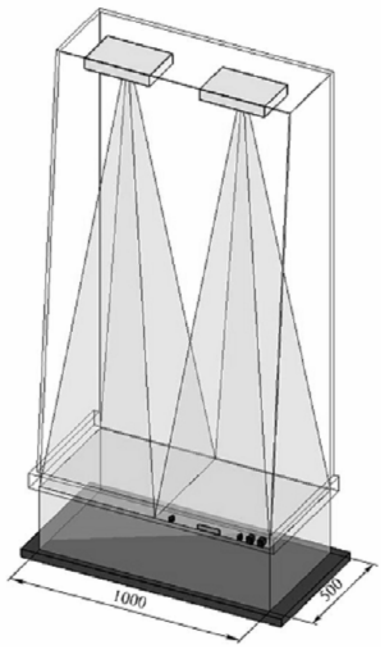

FIGURE 1. Schematic layout of the developed solar simulator for characterization of the large-area HCPV modules .

For correct angular divergence simulation, mentioned above lenses should work in pair with light sources of diameter d=1/100 F. Each source must ensure intensity of light passing through a lens on the level of 1 sun intensity. In turn, for correct sun image simulation, the aperture area of diameter d should be filled up with light as uniformly as possible, if the tested concentrator PV system is based on "imaging" optics. In our design, each illumination source consists of two tube-like flash lamps and a light-tight screen with a hole 20 mm in diameter placed in front of the lamps. In both lamps, identical segments have a share in formation of a light flux passing through the hole. These segments were chosen being the most stable with respect to possible darkening during lamp exploitation. Moreover, at synchronous ignition of the lamps, these segments glow synchronously, what is important, if the pulse duration is of the same order of magnitude as spreading time of the discharge along lamp body. In the case of an "imaging" concentrator system with formation of lamp images on the solar cell surfaces, generation of the photocurrent in the cells will be carried out at one and the same time within different parts of the photosensitive area. Behind each lamp segments, a continuously operating LED is situated allowing for optical alignment of a tested concentrator system before flash illumination. In Figure 2, pictures of the lamp segments during flash and LEDs in a period between flashes are shown, which "are seen" from the simulator measurement plane. The simulated "sun disc" appears to be much more uniform in comparison with the simulator models described in [6, 8]. It is expected that the spatial intensity distribution in the focus of the CPV module will not have an impact on the module fill factor.

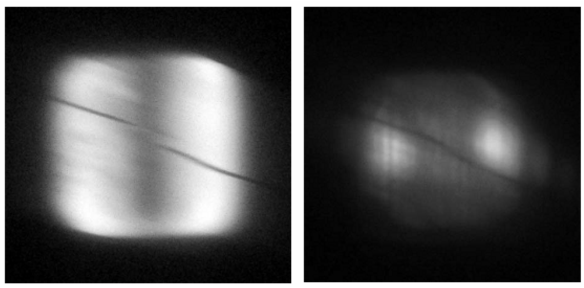

FIGURE 2. "Sun disc" formed in the developed simulator (on the left) and light from the LEDs serving for preliminary alignment of a tested concentrator system.

To evaluate the illumination uniformity in the solar simulator measurement plane, a light sensor similar to an individual concentrator PV unit in the large concentrator modules intended for tests was used. It consisted of a 40x40 mm² Fresnel lens and an InGaP/GaAs/Ge solar cell in its focal plane. The sensor was moved along the simulator measurement plane being aligned normally to the incident light. The short circuit current of the sensor was measured at different points of the measurement plane in steps of 5 cm (without re-aligning). The relative difference in the short circuit currents was used as a measure deviation.

Spatial uniformity across the simulator illumination area of 0.5x1 m^2 was measured to be within +/– 4%.

POWER SUPPLY AND MEASUREMENT UNIT

LC-circuits in the simulator power supply form current pulses through the flash lamps with a flat part (+/– 2%) of about 1 millisecond in duration at total pulse half-width of 3 milliseconds. Light intensity is a replica of the lamp current (see oscillogram for “Light” in Figure 3).This intensity is varied by voltages applied to the flash lamps and, if necessary, by optical transmittance filters. The light pulse periodicity could be set as short as 10 seconds; therefore, in-line productivity of the simulator is evaluated as 250 I-V curves per hour.

The measurement unit includes an active electronic load circuit. In the operating mode “A”, it records one I-V curve at one light pulse. I-V measurements are carried out by sweeping in voltage from reverse to forward bias conditions during the flat part of the light pulse (see oscillogram for “Voltage” and “Current” in Figure 3). This mode is used for characterization of the modules based on the cells with a short life-time of the photogenerated charge carriers (for instance, III-V cells). In the operation mode “B”, the I-V measurement is carried out point by point from flash to flash . Each I-V pair is measured at the end of the flat part of each light pulse (for modules based on the cells with larger carrier life-times, for instance, high-efficiency silicon cells).

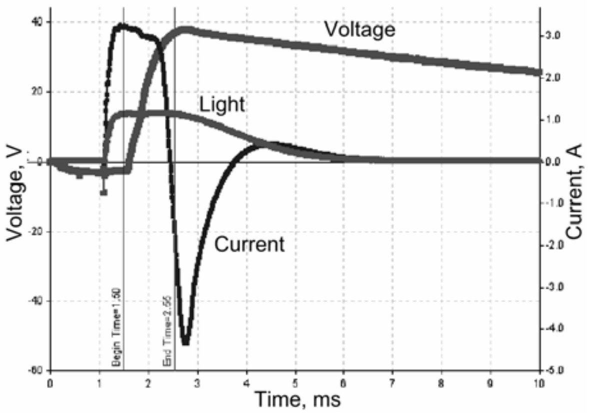

FIGURE 3. Oscillogram of light, voltage and current at I-V measurements in a concentrator PV module 0.5x1 m^2 in size under flash illumination. The I-V measurement is carried out during a plateau on the light curve (light stability is ±2%).

The measurement unit is supplied with a monitor cell to control intensity and to normalize a measured current with respect to slightly non-constant light pulse intensity during I-V curve recording. Also, it includes a relay, which connects the tested module to the circuit for only about 1 second. The last feature is important, if this unit is used at outdoor measurements under continuous solar illumination, so that resistive components of the circuit are under considerable thermal load.

VALIDITY ASSESSMENT

Developed simulator validity has been demonstrated practically in comparative measurements (with the help of the solar simulator and under real sun conditions) of the concentrator modules based on InGaP/GaAs/Ge solar cells and silicone-on-glass Fresnel lens panels. These 0.5x1.0 m^2 HCPV modules included 288 lenses and the same quantity of cells mounted using the “all-glass” technology [5]. In a module, each 24 cells are electrically connected in parallel and 12 groups are connected in series. Also, the two-hold smaller modules were tested. Outdoor and indoor I-V recordings have been carried out by one and the same measurement unit. Arrangement of the modules at outdoor and indoor tests is shown in Figures 4 and 5.

FIGURE 4. HCPV modules 0.5x1.0 and 0.5x0.5 m^2 in size on the roof of the Ioffe Institute at outdoor measurements.

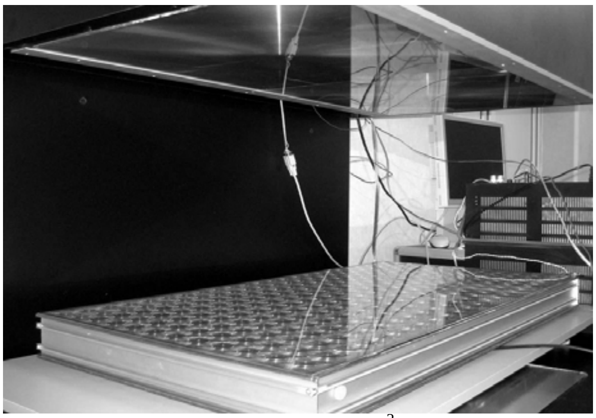

FIGURE 5. HCPV module 0.5x1.0 m^2 in size installed on an adjustable holder of the solar simulator ready for indoor measurements.

The I-V curves recorded outdoors and indoors for a 0.5x1.0 m^2 HCPV module are presented in Figure 6. Solar irradiance was 835 W/m^2. Light intensity under flash illumination was set by using a calibrated outdoors reference cell and its value turned out to be in a good agreement with the measured short circuit current of the module. Fitting in voltage took place automatically, because outdoor experiments were conducted at low enough temperature (-2 C). It is seen from Figure 6 that the developed simulator gives knowledge about the behavior of a CPV system under real sun on the basis of indoor measurements.

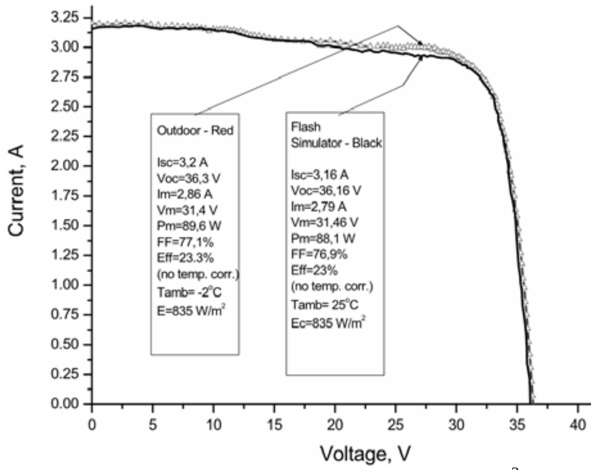

FIGURE 6. Illuminated I-V curves of a 0.5x1.0 m^2 HCPV module. The dashed curve is a result of the outdoor measurements at ambient temperature of -2C; the solid curve has been recorded indoors with the help of the developed solar simulator.

CONCLUSIONS

Description of design and results of test measurements of the flash solar simulator on the basis of two 0.5x0.5 m^2 Fresnel lenses with eliminated effect of the chromatic aberration and reduced absorption in the near infra-red part of light spectrum have been presented. The simulator ensures irradiance level, spectral distribution, light beam divergence and light intensity distribution across a spot image similar to that of the sun. Arrangement of the optical elements ensured a compact structure of the simulator suitable for in-line applications at HCPV module production. Simulator validity has been demonstrated by comparative measurements of the 0.5x1 m^2 in size multilens concentrator modules based on InGaP/GaAs/Ge solar cells and silicone-on-glass Fresnel lens panels.

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REFERENCES

1. V.M.Andreev, E.A.Ionova, V.R.Larionov, V.D.Rumyantsev, M.Z.Shvarts, G.Glenn "Tunnel diode revealing peculiarities at I-V measurements in multijunction III-V solar cells", Proceedings of the IEEE 4th World Conference on Photovoltaic Energy Conversion May 7-12, 2006, Hawaii, pp. 799-802.
2. V.D.Rumyantsev, N.A.Sadchikov, A.E.Chalov, E.A.Ionova, V.R.Larionov, V.M.Andreev, G.R.Smekens, E.W.Merkle "Pilot installation with "all-glass" concentrator PV modules", Proceedings of the 21st European Photovoltaic Solar Energy Conference, Dresden, 2006, pp. 2097-2100.
3. V.D.Rumyantsev, N.A.Sadchikov, A.E.Chalov, E.A.Ionova, D.J.Friedman, G.Glenn "Terrestrial concentrator PV modules based on GaInP/GaAs/Ge tj cells and minilens panels", Proceedings of the IEEE 4th World Conference on Photovoltaic Energy Conversion May 7-12, 2006, Hawaii, pp. 632-635.
4. V.D.Rumyantsev, V.M.Andreev, V.R.Larionov, D.A. Malevskiy, M.Z.Shvarts "Indoor characterization of multijunction concentrator cells under flash illumination with variable spectrum", Proc. of the Fourth Int. Conf. on Solar Concentrators for the Generation of Electricity or Hydrogen, El Escorial, Spain, 2007, pp. 277-280.
5. V. D.Rumyantsev "Terrestrial concentrator PV systems" in: "Concentrator Photovoltaics", Eds.: A.Luque, V.Andreev, Springer Series in Optical Sciences, vol.130, 2007, pp. 151-174.
6. C. Dominguez, I. Anton, G. Sala and M. Martinez. "Description and Validity Assessment of a Solar Simulator for high Concentration PV Modules", 22nd European Photovoltaic Solar Energy Conference, Milan, Italy 2007, pp. 136-139.
7. César Domínguez, Ignacio Antón, and Gabriel Sala "Solar simulator for concentrator photovoltaic systems" Optics Express, Vol. 16, Issue 19, 2008, pp. 14894-14901.
8. Peharz G, Ferrer-Rodrı ´guez JP, Siefer G, Bett AW. "Indoor characterization of CPV modules at Fraunhofer ISE", Proceedings of the 5th International Conference on Solar Concentrators, Palm Desert, CA, 2008.