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A comparative analysis of wind pressure on flat and stair-step constructions of solar plant trackers

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Abstract

The paper presents comparative experimental research of the aerodynamic processes and forces occurring due to airflow moving past by concentrator photovoltaic (CPV) modules assembled on a flat and a stair-step frame. The subsequent analysis of the aerodynamic properties of these design schemes has revealed the significant advantages of stair-step arrangement of CPV modules over the flat ones concerning smaller wind loads affecting the platform. In order to calculate the value of the forces operating on full-size solar installations, values for aerodynamic resistance for different schemes of module arrangement have been obtained. Detailed research of various solar installation models utilizing a wind tunnel and aerodynamic scales is carried out for the first time.

Keywords: Experimental study; Wind loads; PV platform; Force coefficient; Air tunnel; Flow visualization.

1. Introduction

Efficiencies over 45% under the conditions of sunlight concentration have been achieved in multi-junction solar cells (SCs) based on III–V semiconductors [1,2]. The wide application of these SCs under terrestrial conditions is possible only with the use of industrially inexpensive integral optical concentrators capable of focusing the sunlight onto a small surface (2 × 2 mm) of multi-junction SCs [3,4]. To maximize the amount of energy generated, the optical axis of the concentrator photovoltaic cell pair must be precisely oriented towards the Sun. In practice, for concentration ratios of around 1000 suns and above, the accuracy of the mutual positions of the components of this pair and the accuracy of the orientation towards the Sun must be stable and relatively high (at least 0.1°) [5]. Due to these requirements, there is a certain lag in the progress of concentrator photovoltaic (CPV) compared to other approaches aimed at generating electricity from sunlight. However, it shows significant promise for further improving the efficiency. One possible option is enhancing the structure and the constructions of all components of power facilities such as SCs, concentrating modules, and solar tracker constructions (the latter ensure that the CPV system as a whole operates normally).

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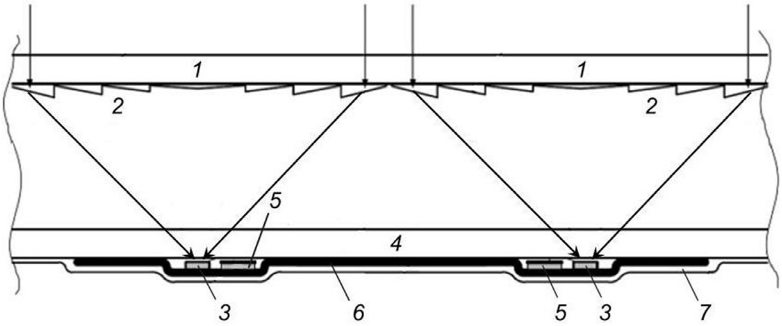

Fig. 1. A schematic cross-section of a SMALFOC-construction module: frontal glass plate (1), silicone Fresnel lenses (2), solar cell (3), rear glass plate (integral protective glass) (4), current-collecting busbar (5), heat-dissipation steel bar (6), laminating ethylene vinyl acetate (EVA) film (7). The arrows mark the path of the optical beams.

The conventional method of arranging the modules on the tracker's frame involves forming a photoreceptive surface of a solar installation as an integral flat panel. At the generated electric power of tens of kilowatts the flat panel consisting of separate CPV modules experiences significant wind loads. As a rule, once a certain wind speed is exceeded, the frame with the modules must be tilted horizontally in order to prevent installation failure. However, even with moderate but time-variable loads, there is, firstly, the risk of fatigue effects in the frame materials and in other mechanical parts of the tracker, and, secondly, such loads cause the error in the platform's orientation towards the Sun to increase [6], which ultimately leads to a significant decrease in the amount of the electric energy generated. Therefore, the problem of reducing wind loads on solar installations with sun-tracking systems is of high priority [7–10].

The goal of the present work is to experimentally establish the influence of wind loads on a platform with concentrating photovoltaic modules for two different schemes of arranging separate modules on the platform.

2. Concentrating photovoltaic systems

The photovoltaics laboratory of the Ioffe Institute has been developing all the components of concentrating photovoltaic systems, including concentrating modules and solar trackers over the recent years [3,4]. The modules that are supposed to be placed on the trackers have the so-called SMALFOC construction [6] which has many similarities with the construction of ordinary flat modules without concentrators both in the type of main materials used and in manufacturing technology. A schematic cross-section of a fragment of such a module is shown in Fig. 1.

In world practice, Fresnel lens concentrators manufactured from a transparent acrylic material by hot stamping are most commonly used in solar concentrator modules. The acrylic is transparent in the visible region but has absorption bands in the near-infrared part of the spectrum. The researchers of the Ioffe Institute suggested using a transparent silicone compound [4] instead of the acrylic. A sheet of silicate glass (which is a cheap, highly transparent and abrasion-resistant material) serves in this case as a mechanical base of the lens panel. A thin layer of silicone is placed on the inner side of the glass for a Fresnel lens profile to be formed on it.

The module has a lens concentrator frontal panel 1, with the solar elements 3 combined into a photoreceptive panel that is distanced from a lens panel by a distance equal to the focal distance of the lenses 2 (see Fig. 1). A panel-type concentrator module with small-sized isolated submodules is thus formed. The photoelements 3 are hermetically sealed and protected from environmental exposure by a simple method using the laminating film *7*. The photoreceptive surface of a standard module measures 480 × 960 mm, while its output voltage is 48 V at a 2.5 A current. These parameters are maintained by 16 series-connected assemblies, each assembly having 8 parallel-connected SCs. Using SCs with efficiencies of about 43% potentially allows obtaining total efficiencies of about 34% for the whole module. To achieve such an efficiency, the image of the solar disk must be precisely focused on the receiving surface element of each photoconverter. For this goal, it is enough to maintain the standard assembling accuracy of each individual module, to keep all modules in fine adjustment on the common base to align their optical axes, to point the platform precisely at the Sun, and, finally, to preserve the stability of these technological parameters during the whole lifetime of a power plant