Chapter 7
Performance Improvement Study of Linear Photovoltaic Systems With Concentration of Solar Radiation

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ABSTRACT

A new type of linear cooled photodetectors is considered, of which in the focal region of the optical concentrator mirrors is installed an array of solar cells operating with the low-ratio solar concentration. This work is focused on the theoretical and experimental substantiation of the efficiency increase of photodetectors under conditions of an optimal combination between solar radiation concentration and heat transfer intensity of photovoltaic cells with heat carriers. The problem of obtaining a high temperature liquid due to the limitations of solar cells is solved by organizing the flow of fluid within the thermal collector channels in the focal region of an additional optical concentrator. A mathematical model of engineering characteristic calculation of the Λ - shaped photodetectors and cost calculation of electrical and thermal energy generation is presented. The research results are used in the development of industrial prototypes of photodetectors with a concentration of solar radiation and low production costs.

INTRODUCTION

Long-term studies on photovoltaic led to the creation of a technology for the production of silicon solar cells with an efficiency close to the theoretical limit $\approx 25\%$. Commercial photovoltaic modules (PV modules) with an efficiency of $\approx 16\%$ have appeared on the market, which dissipate most of the incoming solar energy as heat into the environment. In order to solve this issue, intensive research is being carried out, which allow receiving simultaneously electric and thermal energy. The technology

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and production line of photovoltaic-thermal (PVT) systems was developed, a detailed review of which was presented by Chow (Chow, 2010), and methodology for calculating performance was proposed by Duffe and Bechman (Duffie & Beckman, 2006). The first samples of PVT systems on silicon photocells had a technical limitation on the operating temperature, which conflicted with the aim to obtain a high temperature of heat carriers at the outlet for economic use. The problem was partially solved with the transition to high-temperature GaAs photovoltaic cells, capable of efficiently generating electrical and thermal energy. However, they turned out to be scarce and much more expensive than silicon solar cells, so there was a need to use solar concentration ratio in more than 50-fold to ensure payback.

In Israel, is developing a cogeneration plant based on a paraboloid with an area of ≈ 1m^2 and 400-fold concentration ratio (Kribus et al., 2006). Three-junction InGaP/InGaAs/Ge solar cells are used, which make it possible to obtain a specific electric power of ≈ 170 W/m^2 and thermal ≈ 530 W/m^2 with a ratio of 530/170 ≈ 5.3 and an output coolant temperature ≈ 70 °C. Such systems are too small in power to provide the individual consumer with enough electricity and heat energy.

In Zurich, a three-year project of developing a "DSolar Sunflower" pilot system with a parabolic optical hub of 36 mirrors was completed in 2017 (Airlight, 2017). For a very high (>1500-fold) optical concentration of solar radiation on the limited surface of three-junction GaAs solar cells, it is necessary to use a relatively expensive precision sun tracking system and a high-pressure station with liquid purification filters for cooling the solar cells (Escher, Paredes, Zimmermann, Chin, 2012; Zimmermann et al., 2013). The complex process of manufacturing elliptical mirrors, the low reliability of the cooling system of the solar cells, and the large weight ≈ 18.5 tons reduce the potential for commercialization of the technology.

In the work of Prof. Xu Ji et al., the efficiency of a linear photodetector with silicon solar cells at different radiation concentrations was studied (Ji, Li, Lin et al., 2012). It was noted that the thermal efficiency of the photodetector increased linearly in the range of direct radiation 200 - 1200 W/m^2, and the electrical one only up to 500 W/m^2. The decrease in the rate of growth of electrical efficiency is explained by the negative effect of an increase in the internal series resistance on the no-load voltage.

J.S. Coventry et al., investigated the process of converting solar energy at 30-fold solar concentration ratio on silicon solar cells with a width of 40 mm, placed on a cooled photodetector with a width of 80 mm (Coveny, 2005, pp. 211-222). The low series resistance of solar cells ≈ 0.043 Ohm/cm^2 was achieved due to the creation of narrow gaps between the conductive pins, doping with phosphorus in the area of collecting electrons and a large cross section of electrical contacts. In this case, the peak electric power was ≈ 11% and thermal ≈ 57% with the achievement of the ratio 57/11 ≈ 5.2.

Cogenra Solar (SunPower Corporation) has developed a cogeneration system with linear V-shaped photodetectors in the focal region of concentrator flat mirrors (Forbes Solar, 2017). At the latitude of South Carolina state (≈ 35° N) at 9-fold concentration ratio, photodetectors produce specific electric energy ≈ 168 kWh/m^2 and thermal ≈ 657 kWh/m^2 per year, and the coolant output temperature in the autumn period reaches ≈60 °C. For the first time, a five-year payback of capital costs was proved with the ratio of the generated specific heat and electric energy ≈ 3.9. The peak power of photodetectors with optical concentrators from 14 flat mirrors reached ≈ 100 W/m^2 and ≈ 498 W/m^2 heat power. The disadvantages of the system are large heat losses, the inability to obtain a high output temperature of the liquid and a relatively large unit cost.

The most promising method of working with a low concentration of the sun are solar cells made of n-Si, whose advantage over p-Si is due to the low rate of degradation of performance and low sensitivity to impurities and defects (Untila et al., 2012; Milichko et al., 2016). SunPower Corporation achieved the