ANNOTATION

of the dissertation thesis for the degree of Doctor of Philosophy (PhD) in the educational program "8D06201 – Radioengineering, electronics and telecommunications" by Dosymbetova Gulbakhar

CONCENTRATED PHOTOVOLTAIC SYSTEMS WITH CONTROL AND MONITORING BASED ON THE INTERNET OF THINGS

General characteristics of the work.

The dissertation work is devoted to concentrating photovoltaic systems with an active cooling system using the Internet of Things in order to monitor the state of the system and environmental conditions for making decisions to optimize the operation of the cooling system.

The relevance of the dissertation theme.

There is a lot of interest in concentrating silicon solar panels today due to the increase in the use of solar panels in the world for various purposes. The research and development of new cheap, relatively simple ways to increase the efficiency of photovoltaic cells has a high scientific and practical significance.

Polycrystalline silicon photovoltaic cells are not designed to operate at high concentration degrees. They are used at low and medium concentration degrees. However, in the absence of a good active cooling system in such conditions, photovoltaic cells quickly lose their semiconductor properties.

The cooling systems of photovoltaic installations are divided into passive and active. Passive cooling systems do not use a heat carrier. The heat is dissipated by air without the use of additional devices. Active cooling systems are devices in which a coolant, usually water, circulates through pipes using a pump, thereby taking heat from heated devices.

High energy efficiency requirements are imposed on modern cooling systems. Simple cooling systems based on temperature threshold algorithms do not have high enough efficiency for use in photovoltaic systems. The pump power in such systems does not depend on the heating rate of photovoltaic cells and the power of solar radiation. It is unchangeable and, under certain conditions, reduces the efficiency of the entire system. As a result, it is necessary to create a system that will adapt the pump power to the current temperature and the power of the incident solar radiation.

The dependence of the pump power on the solar radiation power and the current temperature is nonlinear. The temperature depends on the solar radiation power in a non-linear way. As a result, direct calculation of the pump power is difficult. Moreover, when deploying large solar power plants, the amount of data on the temperature of solar panels will increase, and it leads to an increase of the computing resources of the system. It is often difficult or impossible to increase the local computing resources of the system due to financial or other constraints. Then there is a need to create a system with remote access and monitoring for the pump power control system.

This work is aimed at improving the efficiency of silicon polycrystalline photovoltaic cells under low concentration conditions, as well as improving the efficiency of the active cooling system using the Internet of Things.

The main task is to increase the efficiency of modern commercial silicon photovoltaic cells using a Fresnel lens and an active cooling system, as well as to optimize the active cooling system using the Internet of Things.

The purpose of the research is to increase the efficiency of polycrystalline commercial silicon photovoltaic cells using Fresnel lenses at low concentration and optimal operation of the active cooling system using the Internet of Things.

To achieve this goal, it is necessary to solve the following tasks:

- design, assembly and debugging of concentrating photocells using Fresnel lenses and study of the dependence of the short-circuit current on the degree of concentration;
- study of photocell energy generation in conditions of low concentration during the day;
- study of the dynamics of heating and cooling of a photocell at different incident solar radiation and different pump power levels and development of a model for predicting heating and cooling of photocells using neural networks;
- development of a decision-making system based on the Internet of Things in order to select the most optimal mode of operation of the cooling system.

The object of the research is a concentrated polycrystalline silicon solar battery with an active cooling system.

The subject of the research is the photovoltaic effect in conditions of concentrated solar radiation, optical processes occurring in Fresnel lenses, the dynamics of the heating and cooling process of photovoltaic cells in conditions of low concentration, a monitoring and control system using the Internet of Things and optimization of energy systems.

The research methods are:

- experimental study of the optimal distance between the lens and the photovoltaic cell and determination of the concentration degree;
- experimental study of the heating process of photovoltaic cells at different levels of solar radiation power in low concentration conditions;
- experimental study of the cooling process of photovoltaic cells using an active cooling system at different levels of solar radiation power and different pump power;
- modeling of the output power of photovoltaic cells in low concentration conditions using single model;
- prediction of heating and cooling of photovoltaic cells at different solar radiation using neural networks;

The novelty of the work. The novelty and originality of the work lies in the fact that it is the first time:

- the dependence of the short-circuit current of a concentrating polycrystalline silicon solar cell on the incident radiation power and its temperature is experimentally shown;

- an increase in the generated energy by a solar cell was experimentally established at a concentration ratio C_g=8 using a Fresnel lens;

- a monitoring and control system based on the Internet of things and an algorithm for an optimal cooling system for concentrating silicon polycrystalline photovoltaic cells have been developed.

Scientific and practical significance of the work.

The results obtained in this work are significant for increasing the output power of photovoltaic cells. The obtained data can be used to create concentrated polycrystalline silicon photovoltaic cells and active cooling systems for photovoltaic systems.

An increase in the output power of solar panels can be achieved by creating a solar tracking system and installing an optical system to increase the concentration degree of solar rays per unit area of the solar battery. Photovoltaic cells used at high and medium concentration degree, although capable of withstanding high operating temperatures, have not become widespread due to the high cost compared to inexpensive polycrystalline photovoltaic cells. Therefore, at the moment they are not widely used in the energy sector. In this dissertation, a concentrating photovoltaic system using inexpensive polycrystalline silicon photovoltaic cells has been developed.

An increase in the concentration degree of silicon photovoltaic cells leads to a rapid increase in their temperature and, as a result, a decrease in efficiency. The solution to this problem is an active cooling system. However, such cooling systems consume energy, and the final efficiency of the solar battery is formed from the energy generated by solar panels minus the energy for the operation of the cooling system. In this paper, an optimal algorithm of the decision-making system based on the Internet of Things is proposed to reduce the energy consumption of the cooling system, which is based on neural networks.

The main provisions for the defense:

1 The ratio of the short–circuit current of a polycrystalline silicon photocell with a Fresnel lens with a low degree of concentration to the short-circuit current without a lens increases by 1.5-2.2 times;

2 The generated energy of a polycrystalline silicon photocell at a geometric concentration degree of C_g =8 using a Fresnel lens increases by 51% during the day compared to the generated energy of a photocell without a lens;

3 The optimal operating mode of the cooling system, determined using the developed decision-making system based on forecasting using neural networks and the Internet of Things, reduces the energy consumption of the cooling system by 62% compared to the algorithm based on threshold temperature levels.

The reliability and validity of the results obtained are confirmed by the presence of publications in foreign journals with an impact factor and in publications recommended by the Committee for Quality Assurance in the Field of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, and in the proceedings of international scientific conferences of the near and far abroad. The experimental data obtained during the implementation of the project are in good agreement with the calculations obtained on the basis of the proposed model.

The author's personal contribution is that the entire scope of the dissertation work, the choice of the research method, the assembly of experimental installations, the manufacture of printed circuit boards for the monitoring and control system of the cooling system, training and forecasting of neural network models, conducting experiments and analyzing the data obtained, the development of a mathematical model of photovoltaic cells in low concentration conditions were performed by the author independently. The formulation of tasks and discussion of the results were carried out jointly with scientific supervisors.

Approbation of the dissertation. The results obtained in the dissertation work were published, reported and discussed:

Publications with an impact factor on the Thomson Reuters database or in publications included in the international scientific database Scopus:

1. Dosymbetova G. Mekhilef S, Orynbassar S, Kapparova A, Saymbetov A, Nurgaliyev M, Zholamanov B, Kuttybay N, Manakov S, Svanbayev Y, Koshkarbay N. Neural Network based Active Cooling System with IoT Monitoring and Control for LCPV Silicon Solar Cells // IEEE Access -2023. – Vol.11. – P. 52585 – 52602.
2. Dosymbetova G. Mekhilef S, Saymbetov A, Nurgaliyev M, Kapparova A, Manakov S, Orynbassar S, Kuttybay N, Svanbayev Y, Yuldoshev I, Zholamanov B, Koshkarbay N. Modeling and Simulation of Silicon Solar Cells under Low Concentration Conditions //Energies. – 2022. – Vol. 15. – №. 24. – P. 9404. https://doi.org/10.3390/en15249404

Publications in publications recommended by the Committee for Quality Assurance in the Field of Science and Higher Education MSHE RK:

1. Dosymbetova, G. B., Svanbayev Ye.A., Zhuman, G. B., Nurgaliyev, M. K., Saymbetov, A. K. Development of concentrating silicon solar cells. News of the national academy of sciences of the republic of Kazakhstan physico-mathematical series. – 2021, – Vol. 4. – №. 338. – P. 25-30.

Publications in the media theses and reports:

1. Dosymbetova G.B., Nurgaliyev M.K., Tukymbekov D., Kuttybay N.B. Concentrated silicon solar cells using Fresnel lenses //International conference of students and young scientists "Farabi Alemi". – Almaty. – 2020. – P. 276.

Copyright Certificate

Dosymbetova G.B., Nurgaliyev M.K., Saymbetov A.K., Kuttybay N.B., Zholamanov B.N., Orynbassar S.O., Kapparova A.A. Concentrated silicon solar cells with an active cooling system based on the Internet of Things // Copyright certificate, 2023. No. 34937.

The volume and structure of the dissertation.

The dissertation work consists of an introduction, 3 sections, a conclusion and 125 references, contains 103 pages of the main computer text, including 76 figures, 3 tables and 3 appendixes.

The first chapter of the dissertation is devoted to a review of the literature on modern concentrating photovoltaic systems and active and passive cooling systems.

The second chapter of the dissertation presents studies of the dependence of the temperature of a photovoltaic cell on the power of incident solar radiation, an optical system based on a Fresnel lens and a single-diode model of a photovoltaic cell.

The third chapter is devoted to optimizing the cooling system using wireless control and monitoring using the Internet of Things.

The relationship of the topic of the dissertation work with the plans of research programs

The dissertation work was carried out in accordance with the plans of the research work (R&D) for 2018-2020, individual registration number (IRN) AP05132464 "Development of an intelligent autonomous system for wireless control and monitoring of street lighting".