Evaluation of new possibilities of using thermoelectric generators in systems of renewable energy sources (RES)

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Abstract. This paper presents an analysis of the application of new technologies in the design of thermoelectric cooling systems, presented the results of the comparative analysis of classical thermoelectric system and the thermoelectric system with the spatial orientation of the heat transfer sides. New thermoelectric systems are beginning to compete with traditional ways of energy transformation up to several hundred watts. To extend the range of applications of thermoelectric systems, it is necessary to use new design methods and new design solutions that will more effectively convert heat losses into useful energy for future use. This paper presents the results of a comparative analysis of conventional thermoelectric module and the thermoelectric module with the spatial orientation of the parties. It is shown that the efficiency of the thermoelectric module with the spatial orientation of the parties in the current in 4A 36% higher compared to the classic thermoelectric module and 43% higher when the current is 8A. The results of the research have shown that the efficiency of the thermoelectric modules to a greater extent influence not electrophysical characteristics of thermoelectric junctions, and the technical decisions when designing and designing. Studies have shown that further work to increase the efficiency of thermoelectric systems should be conducted in the field of improvement of structure of the thermoelectric modules. Using the known topology emitted or absorbed heat from the thermoelectric module can be moved to side to distribute it over a larger area or concentrate on a smaller area. With the increase of its efficiency, thermoelectric modules can compete with traditional heat pumps in the field of higher capacity and will be able to expand your range of applications.

Introduction

Energy consumption grows annually and significant part of it turns into heat which being disposed in to the environment with no benefits. United Nations Development Programme estimates wastes of energy in Russian Federation and power requirement of it is economy to be 1.5-2.5 times higher than in the Europe despite latter having higher energy consumption per capita [1]. Methods of dealing with heat losses can be conditionally divided into passive and active. Passive systems usually reduce heat losses via thermal insulation of buildings using modern materials with high thermal insulation characteristics. Active system relies on renewable energy (RES), usually external source being used. With the development of new technologies in the electronics industry priorities for using different types of RES have changed. In the first place is the solar energy, the second - bioenergy. Wind energy gave way to other renewable energy sources, mainly due to the fact that many wind energy projects were
not brought to the industrial stage, since obtaining wind energy was proven to be more difficult and expensive than anticipated [2].

Development, production and introduction of RES, which is based on using internal energy resource, is not widespread not only in Russia, but throughout the world. These are mainly devices operating on the concept of "heat pump", one of the most extensive use of these devices in ventilation systems, as a heat recovery units. Its work is based on the concept of energy transfer from one body to another, and the body from which energy is taken can have a temperature lower than the body to which energy is transferred. In recent years, particular interest has been shown in systems that operate on the basis of thermoelectric energy. Expansion of technological capabilities and emergence of new thermoelectric materials led to the creation of new thermoelements with an increased energy conversion efficiency [3].

New thermoelectric systems begin to compete with traditional methods of energy conversion up to several hundred watts, and for objects with special requirements on weight, vibration, and reliability characteristics they have almost no competitors [4]. The advantage of thermoelectric systems compared to traditional systems: unlimited service life, no moving parts, silent operation, environmental soundness, versatility in terms of heat supply and removal methods and the possibility of recovering the waste heat [5-6]. Thermoelectric elements provide new opportunities in the design of special systems that convert heat losses into electrical energy for further use [7].

Material and research methods

Thermoelectric heat pump design is based on a thermoelectric module with radiators. The thermoelectric module has two heat transfer surfaces, one in contact with the medium from which energy is taken, the other in contact with the medium to which energy is transmitted. Figure 1 shows a view of a classic thermoelectric module with radiators.

![Figure 1. Classic thermoelectric module with heat sinks 1 - thermoelectric junctions, 2 - heat radiating side, 3 - heat absorbing side, 4 - heating radiator, 5 - cooling radiator.](image)

Analysis of the literature data [8-13] showed that the efficiency of thermoelectric modules is influenced to a greater extent by technical solutions in the design and engineering rather than by the electrophysical characteristics of thermoelectric junctions. At this stage in the development of thermoelectric instrumentation, external technical losses in real systems are comparable to internal losses in thermoelements, mainly due to the reciprocal influence of heat transfer plates and the thermal conductivity of thermoelectric junctions. The increase in the efficiency of thermoelectric systems is mainly achieved by improving the design of heating and cooling radiators. Since the area of heat transfer plates in classical thermoelectric modules remains unchanged, efforts to increase the efficiency in this area do not give significant results. Therefore, efforts to further increase the efficiency should be conducted in the field of application of new technical solutions in the design of thermoelectric modules themselves.

The design of a classical thermoelectric module is a three-dimensional figure, where current-conducting paths are sequentially formed between two identical parallel, small planes, which are con-
nected in series by columns of n- and p-type semiconductors. The distance between the plates is determined by the technical capabilities of the applied technologies for the manufacture of semiconductor columns (1-3 mm).

The goal of our research was to develop and conduct a comparative analysis of a thermoelectric module with a change in the spatial orientation of heat transfer zones and with the possibility of significantly increasing the distance between heat transfer zones.

We have developed a new method of manufacturing a spatially oriented thermoelectric module [14]. In contrast to the classical technology, we transfer a three-dimensional figure into a plane and create a module on this plane, on a part of the plane, n-type semiconductors on another part of the p-type. The size of the plane may be large, the planes may be spatially oriented, parts of the planes may not be the same and the distance between the parts of the planes may be different. We carry out the process of fixing n- and p-type semiconductor thermoelements on a dielectric substrate (plane), on which using paste with low resistivity and a method of net-screen printing we pre-appliey connecting tracks for same elements and switching for different elements. Then, we apply barrier tracks using dielectric paste to form grooves (cells) between connecting and switching tracks. In the grooves (cells) are applied paste to form semiconductor tracks made on the basis of n-type and p-type semiconductors, which are then subjected to sintering under pressure.

A general view of a new type of thermoelectric module is shown in Figure 2.

![Figure 2. General view of a new type of thermoelectric module: 1 - dielectric substrate made of ceramics, polyethylene terephthalate (PETE), polyamide, a metal with a dielectric coating, 2 - connecting lanes, 3 - switching lanes, 4 - grooves (cells), 5 - barrier paths, 6 - semiconductor paths of n-type conductivity and p-type conductivity, 7 - current-carrying wires.](image)

For the experiments, two samples of thermoelectric modules were made, one of classical type, the second with spatial orientation. Both samples were made on an aluminum substrate with a dielectric coating, bismuth telluride (Bi\(_2\)Te\(_3\)) was used as a thermoelectric material and the number of junctions in both samples was the same (128 junctions). In the sample with spatial orientation, the heat transfer surfaces were separated in a parallel plane, with the area of the heat absorbing side increased by 2 times compared with the heat-radiating side. In their work, a number of scientists [15-17] applying new technical solutions in the design and engineering of radiators, noted that this ratio increases the efficiency of thermoelectric modules.

Figure 3 shows a view of a thermoelectric module with a spatial orientation of the sides and radiators.
Figure 3. Thermoelectric module with a spatial orientation of the parties with radiators
1 - thermoelectric junctions, 2 - heat-radiating side, 3 - heat-absorbing side, 4 - heating radiator, 5 - cooling radiators.

Comparative analysis was carried out on a specialized stand in the laboratory of the “Modern Heating Equipment” of INRTU, the voltage and current readings of the thermoelectric modules were recorded with the universal digital device B7-28, the readings of the transfer medium temperature were measured with thermocouples and recorded with the TPM151 instruments and the "OWEN" software package.

Results and discussion

For comparative analysis, the heat radiating side and the heat absorbing side of both samples were immersed in running water at a temperature of 20 °C. Measurements recorded the heating and temperature gradient at currents $I_1=4$A and $I_2=8$A.

Figures 4 and 5 show the graphs of cooling and heating temperature gradients at a current of $I_1=4$A and $I_2=8$A with a classic thermoelectric module. From the graphs can be seen that the gradient of cooling and heating temperatures differs by 2.5 and 3 times, which corresponds to the results that were obtained by applying constructive solutions for designing radiators. With increasing current load, the efficiency of thermoelectric modules decreases, which was also confirmed by us.
Figure 4. Graph of temperature gradient of the cooling and heating when the current $I_1=4\, \text{A}$ with classic thermoelectric module.

Figure 5. Graph of temperature gradient of the cooling and heating when the $I_2=8\, \text{A}$ with classic thermoelectric module.

In figures 6 and 7 shows the graphs of the gradient of cooling and heating temperatures at a current of $I_1=4\, \text{A}$ and $I_2=8\, \text{A}$ with a thermoelectric module, in which the heat transfer sides are spatially separated. As seen from the graphs that the difference in the gradient of cooling and heating temperatures is in the range from 1.6 to 1.7 times, while the efficiency of the thermoelectric module does not significantly change with increasing current.
Figure 6. Graph of temperature gradient of the cooling and heating when the current $I_1=4A$ and spatially oriented thermoelectric module.

Figure 7. Graph of temperature gradient of the cooling and heating when the current $I_2=8A$ and spatially oriented thermoelectric module.

The presented graphs show that the efficiency of a spatially oriented module with a current load of 4A is 36% higher than the classical thermoelectric module and 43% higher with a current load of 8A, which once again confirms that the efficiency of thermoelectric modules is largely influenced by technical solutions in the design and engineering rather than by the electrophysical characteristics of thermoelectric junctions.

Conclusion

From the results it can be seen that work in the field of improving devices for heat dissipation from the area of the heat transfer sides of thermoelectric modules has practically exhausted its possibilities. Further work to increase efficiency should be carried out in the field of designing the structures of thermoelectric modules themselves. Using known topologies, the heat radiated or absorbed from the
thermoelectric module can be moved to the side, distributed over a larger area or contrariwise concentrated on a smaller area [18-19]. Using the new technology of manufacturing thermoelectric modules, it becomes possible to completely remove the reciprocal influence of the hot and cold sides, possibly increasing the heat dissipation area within very wide limits. With an increase in its efficiency, thermoelectric modules will be able to compete with traditional heat pumps in the field of higher power and will be able to expand their range of applications.

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