Development of an experimental model of a tourist thermoelectric generator and researching ways to increase its efficiency

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Abstract. The paper describes the development of an experimental model of a tourist thermoelectric generator (TTEG). TTEG is a compact portable thermoelectric device that provides direct conversion of thermal energy into electricity and is designed to boil water and charge mobile devices in camp conditions. This paper describes the model of the developed TTEG and provides an analysis of its design. The operational conditions of the TTEG are determined and the ways of optimizing its design are investigated. The main requirements for the developed TTEG model are identified in order to increase the efficiency of the device. The application of the electric load control unit with the function of the maximum power point tracking (MPPT) is described.

1. Introduction

Every year more and more people spend time in nature and are engaged in active tourism. When traveling, tourists should not be limited in using electronic equipment. It is necessary to provide the possibility of recharging the batteries of electronic devices during the trip. Existing solutions to the device charging problem in travel conditions are solar panels, external batteries, dynamos. However, solar panels have low efficiency and are not used in dark and cloudy weather. External batteries after their discharge are also useless. Using a dynamo will make the user spend his personal time and energy. At the same time, camping cooking equipment is being upgraded. To replace the heavy metal pots, more and more often comes light, durable, comfortable cooking cups. High-tech and multifunctional equipment is aimed to make the outdoors experience more comfortable. The solution proposed in this article: the development of a tourist thermoelectric generator (TTEG). This device should solve two problems at the same time: cooking and charging the batteries of mobile devices in camping conditions.

2. General principle and design analysis
2.1. TTЭГ Operation principle of TTEG

Tourist thermoelectric generator (TTEG) is a thermoelectric device that converts thermal energy into electricity. The principle of operation of this device is based on the Seebeck effect. The Seebeck effect occurs when a temperature difference across a conductor provides a voltage at the conductor ends. The Seebeck effect appears due to the thermal diffusion which provokes the motion of the charge carriers (electrons or holes) across (or against) temperature difference in the conductors [1]. In camping conditions, the temperature difference can be achieved due to the flame of a bonfire or gas burner for the hot side and due to the water heated for cooking for the cold side.

The main element of TTEG is a thermoelectric module (TEM) (Figure 1). A thermoelectric module is a device that converts thermal energy into electrical energy [2]. The main feature of TEM is direct energy conversion, without additional mechanical and other intermediate transformations. TEM has no moving parts, which leads to its high reliability. The reliability of TEM is proportionally dependent on stress-temperature relationship. Although the rise in temperature and the higher difference between the cold and hot sides is key to the effectiveness of the device, it also challenges the reliability of the TE module. Practically, it is observed that the module fails when the stress exceeds the strength of the material at a certain temperature.

Figure 1. Typical construction of TEM

2.2. Analysis and development of TTEG design

During the development of TTEG, an analysis of various designs of tourist equipment was carried out, including direct analogs of TTEG presented on the market [3-5]. Based on the results of the analysis and experimental studies, it was concluded that the concept with the location of the thermoelectric module at the bottom of the pot (Figure 2) is the most energy-efficient due to the fact that more heat passes through the TEM, thereby generating more electrical energy. For example, charging furnaces [4] have modules on its sides. Also, this concept is multifunctional - it allows to simultaneously boil water for cooking and generate electricity. The ability to work from the flame of a gas burner makes the generator applicable in many weather and climatic conditions, in areas with no wood fuel, in snowy areas. The presence of a radiator will increase the amount of heat absorbed by the heat exchanger and reduce gas consumption.
The block diagram of the described concept is presented in Figure 3. This diagram shows the main parts of the device under development and explains the estimated interrelation of the parameters.
3. Development of a power control unit

The maximum output power generated by the TTEG depends on many external and internal parameters such as: the temperature difference between the hot and cold sides of the TEM, the internal resistance of the module, and the magnitude of the external load. The constancy of the listed parameters cannot be achieved under actual operating conditions of the device. For this reason, in the existing analogs of this device, the removal of the electric power of the TEM is inefficient.

For efficient transmission of generated electricity to the consumer, it is necessary to ensure continuous operation of the TEM at the point of maximum power. To solve this problem, it is proposed to use the power control unit (PCU) with the function of tracking the maximum power point (MPPT). The functional block diagram of the PCU is shown in Figure 4. The work [6] experimentally confirms the efficiency of using the MPPT controller for a powerful thermoelectric generator. The papers [7,8] describe MPPT technology and the problems of development and design of such devices.

![Figure 4. PCU function block diagram](image)

Also, the PCU must contain a built-in rechargeable battery, which will allow constantly accumulate the received electrical energy during the operation of the TTEG.

3.1. MPPT controller

The operation of the MPPT controller is based on the maximum power point tracking algorithm - the algorithm of the electrical converter operation used to increase the energy efficiency of photovoltaic and thermoelectric modules. The operation of MPPT controller is based on the maximum power point tracking algorithm - the algorithm of the electrical converter operation used to increase the energy efficiency of photovoltaic and thermoelectric modules. MPPT converter performs continuously fine-tune of equivalent resistance of the system, to ensure the operation of the TE modules in the maximum output power mode under conditions of changing internal and external parameters of the system, such as: temperature gradient, internal resistance of the modules, load resistance. There are many MPPT algorithms and their applications have been considered by different researchers to date. The most widely used of them are constant voltage method [9], perturb and observe (P&O) algorithm [10] incremental conductance algorithm [11], fuzzy control method [12] and etc.

The internal structure of the PCU with the MPPT function and its connection to the TEM and the load are shown in Figure 5.
The thermoelectric module and load are connected via a DC-DC converter. The maximum power point tracking device continuously detects changes in the current and voltage of the thermoelectric module and adjusts the PWM duty cycle of the converter to obtain match the resistance of module and load.

3.2. Battery management module
The PCU must provide control of battery charge, implement a multi-stage charging method, which will protect and extend the life of the lithium-ion battery. The battery management module is designed to control the battery charge. This module realizes a three-stage charging method that can precisely control the charging process to achieve the best state of charge [13]. This charging method protects and extends the life of lithium-ion batteries. A schematic diagram of the charging process is shown in Figure 6.

The lithium-ion battery has a standard voltage of 3.7 V and a capacity of 5000 mAh, which allows charging most digital products.
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