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A Novel Thermoelectric Generation System with Thermal Switch

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Abstract

The stability of output performance plays a very important role in the thermoelectric generation (TEG) system, but the fluctuation problem of heat source widely exists in the industry which releases the waste heat, and the fluctuating process will cause the instability and low efficiency of the TEG system. In this article, a novel TEG system with thermal switch was proposed to solve this serious problem. In order to get the detailed characteristics of the TEG system with thermal switch, experimental and dynamic modelling methods were used. The experimental and modelling results show that the thermal switch can efficiently reduce the temperature fluctuation and increase the output power and efficiency of the TEG system, and there is an optimal turning on temperature and turning off temperature to maximally increase the output power and electricity efficiency of the TEG system. The comparison between the numerical data and the experimental results has approved the reasonability of the dynamic model.

Keywords: Thermoelectric generation; Heat source fluctuation; Thermal switch; Dynamic model.

1. Introduction

Nowadays, the study on green energy technology has already attracted extensive attention due to the growing energy and environment crises [1-3]. As an entire solid-state energy conversion process with many merits, thermoelectric generation (TEG) is a promising technology which can convert waste heat into electricity directly by thermoelectric (TE) materials [4]. A typical TE device is always environmentally-friendly, quiet, reliable, compact, and has a long operating life. Because of these advantages, the TEG technology can be used to comprehensively utilize different types of heat sources. However, owing to the fluctuation of the heat source, the hot side temperature of TEG ($T_{sc,h}$) is not always stable, which will degrade the output performance dramatically. In order to improve the system efficiency and stability, based on the basic concept of thermal switch proposed by McCarty et al. [5, 6], a new TEG

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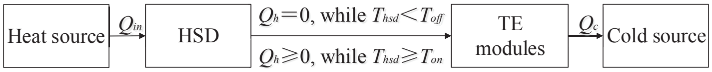

Fig. 1 Schematic diagram of the TEG system with thermal switch

system with thermal switch was proposed in this paper.

The schematic diagram of the new TEG system with thermal switch is shown in Fig. 1. The turning on and turning off temperature of the thermal switch are preset as T_{on} and T_{off} respectively. When the temperature of heat storage device (HSD) T_{hsd} reaches T_{on}, the HSD will contact with the TE modules immediately, while the HSD separates with the TE modules as soon as T_{hsd} drops below T_{off}. After that, T_{hsd} will reach T_{on} again, and so forth. In particular, the HSD absorbs heat from heat source all the time no matter whether the thermal switch is turned on or not. Therefore, the fundamental idea of the thermal switch is to keep the TE module always working at its high efficiency range.

2. Modeling and simulation analysis

2.1 Modeling

The heat leakage from the TEG system to surrounding, radiative and convection heat losses inside the module are neglected; the properties of all the materials are assumed to be constant except for the semiconductor; each face of TEG is well contact, and the thermal contact resistance is neglected. Based on these simplifying assumptions, a one-dimensional dynamic model (Fig. 2) is established as follow:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + q \quad (1)$$

where ρ, c, x, λ, q and T are the density, specific heat capacity, heat transfer direction, thermal conductivity, inner heat source and temperature of different materials, respectively. t is the time.

2.2 Simulation analysis: with and without thermal switch

In simulation process, the input power of heat source is assumed to be sinusoidal variation

$$Q_{in} = 1000 + 1000\sin(0.005t) \quad (2)$$

and R_L is assumed to be equal to the inner resistance, the whole simulation time is one hour. For the new TEG system, T_{on} and T_{off} are preset as 543K and 523K respectively.

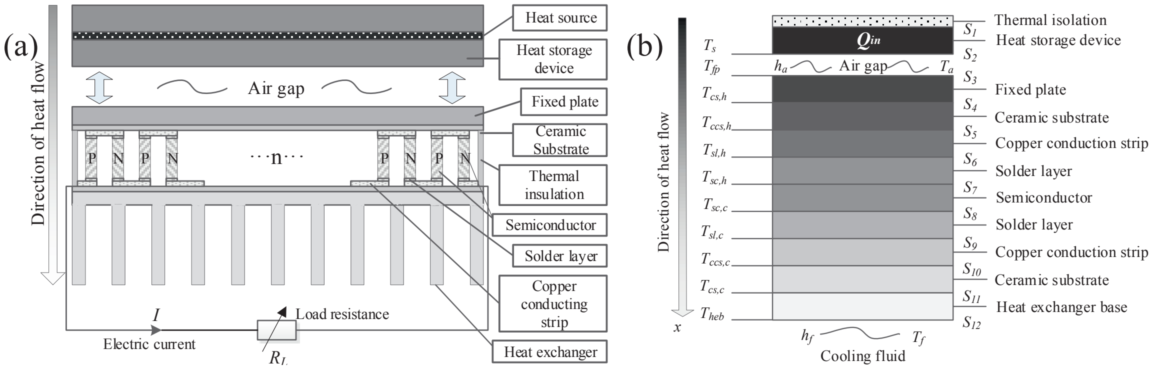

Fig. 2 The physical model (a) and the simplified heat flow model (b) of the new TEG system with thermal switch

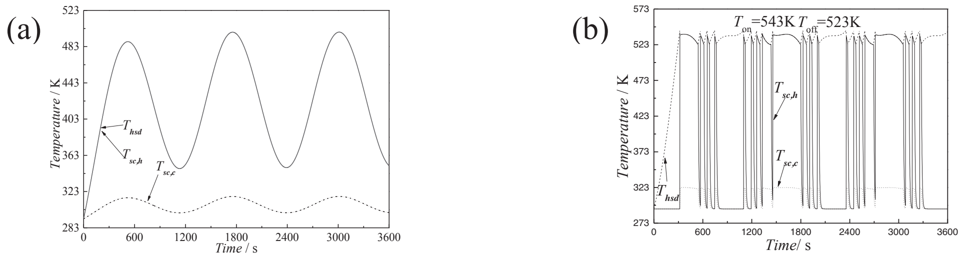

Fig. 3 End-face temperature of the ordinary (a) and the new (b) TEG systems versus time in simulation

As shown in Fig. 3, we can see that the amplitude of cold side temperature is obviously smaller than that of hot side; the hot side temperature ($T_{sc,h}$) of the new TEG system can maintain a relative high value, which will lead to a bigger temperature difference between the two sides and thus a higher output power. The total electricity efficiency of the new TEG system (3.78%) is higher than that of the ordinary one (2.93%); the output power of the new TEG system can maintain a relative high and slow variable value.

3 Experimental

The integrated experimental platform is shown in Fig. 4a. The heat source fluctuation is set as approximately sinusoidal variation (Fig. 4b). The test of each experiment lasts one hour. T_{on} and T_{off} were preset as 533K and 523K respectively. From Fig. 5, we can see that, $T_{sc,h}$ follows the fluctuation mode of the T_{hsd} for the ordinary TEG system, while it can't always close to the T_{hsd} for the new system. $T_{sc,h}$ of the new TEG system can maintain a higher value than the ordinary one with a maximum value difference of about 40K. The output voltage and power of the ordinary one are much lower than 5V and 6W within the testing time, respectively. While the new one can maintain steady and high output voltage and power value about 6.4V and 10W within an interval of about 400s, respectively. In fact, T_{on} and T_{off} should be selected carefully, because there is an optimal combination value of T_{on} and T_{off}, as shown on Table 1.

Table 1. Total efficiency and increase amplitude compared to ordinary TEG system within 1h system running

TEG system	T_{on} /K	T_{off} /K	Total output power/kJ	Total electric efficiency/%	Increase amplitude/%
Without thermal switch	/	/	15.04	0.6442	/
With thermal switch	533	523	15.89	0.6806	5.6504

533	513	16.24	0.6956	7.9789
523	513	16.83	0.7209	11.9062

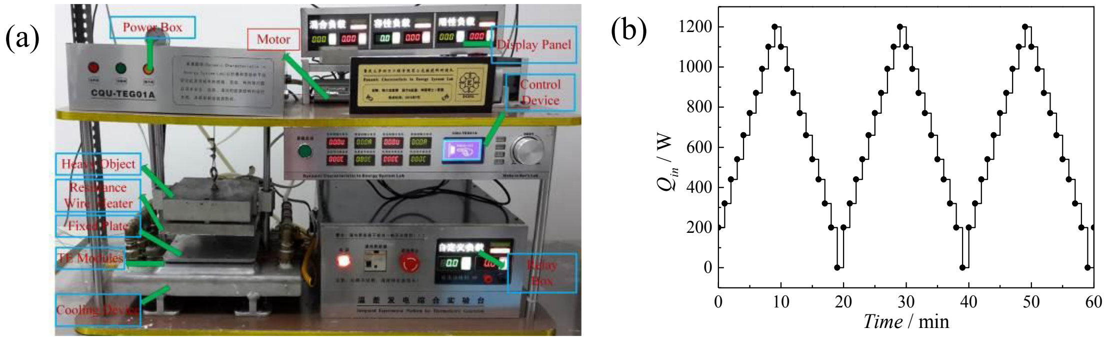

Fig. 4 Integrated experimental platform (a) and input power (b) for the new TEG system

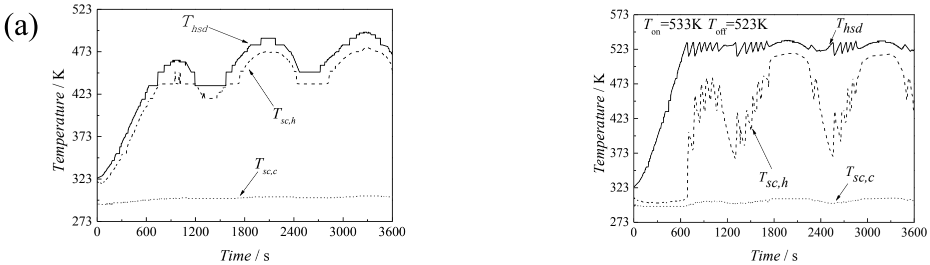

Fig. 5 End-face temperature of the ordinary (a) and the new (b) TEG systems versus time in experimental test

4. Conclusion

In this study, a new thermal switch concept was put forward to improve the output performance of TEG system with fluctuating heat source. A dynamic model was established and solved with finite volume algorithm. Through the simulation and experiment analysis, it is found that the simulated total electricity efficiency of the new TEG system (3.78%) is higher than that of the ordinary one (2.93%); when T_{on}=523K and T_{off}=513K, the experimental output power with a voltage above 5V accounts for 74.39% of the total output electric energy for the new TEG system, while the ordinary one only accounts for 33.05%, the total electric efficiency and its increase amplitude of the new one are 0.7209% and 11.9062% respectively. It is thus verified that the new TEG system with thermal switch is a promising technology. As a future work, a compact, sensitive and adjustable actuating unit of thermal switch will be used to simplify the thermal switch system and make it more economic and practical, by applying heat pipe technique, shape memory alloy technique and liquid metal technique etc.

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Biography

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