Journal of King Saud University – Engineering Sciences (2016) xxx, xxx–xxx

King Saud University

Journal of King Saud University – Engineering Sciences

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Design optimization of a large-scale thermoelectric generator

O.M. Al-Habahbeh *, A. Mohammad, A. Al-khalidi, M. Khanfer, M. Obeid

Department of Mechatronics Engineering, Faculty of Engineering and Technology, The University of Jordan, Amman 11942, Jordan

Received 30 October 2015; accepted 26 January 2016

KEYWORDS

Thermoelectric generator;
TEG optimization;
Concentrated solar power

Abstract The optimum implementation of a thermoelectric generator (TEG) is investigated. In order to study the feasibility of such system, a model for a large-scale TEG is designed and optimized to convert thermal energy into electricity. The mathematical formulation of the system comprising multiple TEG modules is modeled and simulated. It is assumed that the source of the thermal energy comes from concentrated solar receiver. Temperature solutions and heat transfer coefficients are obtained. The major geometrical and thermal parameters affecting the efficiency of the system are identified and optimized for best performance. Design aspects, such as the leg length, and heat transfer conditions have a significant impact on generated output power and efficiency.
© 2016 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

The fluctuating oil prices, concerns about climate, and the depletion of natural resources have drawn attention to renewable energy technology. Furthermore, it is proved that the cost of solar energy will be less than the cost of fossil fuel energy if the indirect cost of the environmental and health damages is included (Almasoud and Gandayh, 2015). An appealing way to generate renewable energy directly from the sun is the use of thermoelectric generator (TEG). In addition to being traditionally used to recover waste heat not high enough for conventional power cycles, it could also compete with photovoltaics if combined with concentrated solar thermal power. One advantage of the latter application is that it does not require the same large area as the case with photovoltaics. However, the TEG efficiency is limited due to its thermal and electrical properties being dependent on each other. Nevertheless, its solid state scalable technology makes it appealing and even more efficient in selective applications. Thermocouple is composed of two integrated intersections of different metals or alloys. When the two junctions are at different temperatures, a low voltage is created. This phenomenon is called the Seebeck effect.

For the purpose of classifying thermoelectric materials, three major parameters are considered: Electrical conductivity

* Corresponding author.
E-mail addresses: o.habahbeh@ju.edu.jo (O.M. Al-Habahbeh), anazzal2004@hotmail.com (A. Mohammad), ahmad.alkhalidi1@gmail.com (A. Al-khalidi), mkhanfer@yahoo.com (M. Khanfer), odai_abeed@hotmail.com (M. Obeid).
Peer review under responsibility of King Saud University.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2016.01.007
1018-3639 © 2016 The Authors. Production and hosting by Elsevier B.V. on behalf of King Saud University.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Please cite this article in press as: Al-Habahbeh, O.M. et al. Design optimization of a large-scale thermoelectric generator. Journal of King Saud University – Engineering Sciences (2016), http://dx.doi.org/10.1016/j.jksues.2016.01.007

σ, thermal conductivity λ, and Seebeck coefficient α (Nolas et al., 2001). A large number of studies focused on the performance of thermal generators over the past decades. Thermal conversion heat engines are described according to the laws of thermodynamics. The energy conservation statement applied to the hot and cold junctions involves four quantities associated with the various energy transport mechanisms (Decher, 1997). These quantities include thermal output, Internal input from resistive heating, electrical energy input of thermoelectric power, and thermal input from conduction. For a fixed set of temperatures and choice of p and n materials, the efficiency depends only on the normalized load resistance $\mu = R_L/R$ (Decher, 1997). Small electrical resistance of the semiconductor helps to increase power output, however, this property cannot be easily manipulated (Yu and Zhao, 2007).

Multiple elements of thermal generators were studied by Chen et al. (2002) with the irreversibility of limited heat transfer rate. Taking the effect of heat transfer and the number of elements in the performance analysis, they concluded that the optimized structure parameters must be selected from the viewpoints of improvement compromise between power output and efficiency in order to get the best performance.

Numerical analysis is an efficient way to quantify the thermal performance of generators. In particular, the numerical approach is able to provide more detailed information about the analytical methods (Yu and Zhao, 2007). LeBlanc (2014) dealt with the product development of TEG and the challenges in materials development and systems engineering. He examined several factors that affect the commercial feasibility of TEG applications. However, his approach was not specific enough to provide a practical case scenario. Roy et al. (2013) described a method to design and optimize a large-scale TEG system with a non-constant heat source. Their method requires predefining the thermal and electrical parameters of the thermoelectric generator, prior to finding the optimized parameters.

In this work, a feasible TEG application is optimized, such that the critical parameters are determined by the simulation of the model, and thereby, do not need to be predefined. The analysis of this application is conducted using a large-scale solar TEG model. The model consists of a large number of TEG modules as shown in Fig. 1. The large-scale model has a tube length of up to 10 m. The modules are sandwiched between heat transfer tubes, which carry the warm input and cold output flows of the working fluid. The details of the model formulation are presented in the next section.

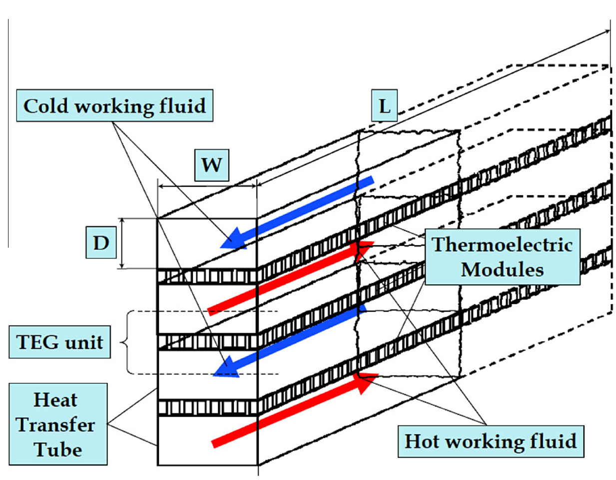

Figure 1 Configuration of the large-scale TEG (Bitschi, 2009).

2. TEG model formulation

The TEG model is based on the steps shown in Fig. 2. The two main components of the TEG are the modules and the heat transfer system. A numerical one-dimensional TEG model is developed using average parameters. A counter-flow parallel-plate heat exchanger is used for heat transfer. The proposed model is based on the following assumptions (Bitschi, 2009):

- Axial heat conduction within the thermocouples is ignored, as transverse conduction along the thermocouples will be dominant.
- Surfaces of the TEG exposed to ambient air are thermally insulated.
- Thermal contact resistance between the heat exchanger plates and the modules is ignored.

The energy flow statement applied to the hot and cold junctions of the TEG involves four quantities associated with different energy transport mechanisms (Decher, 1997). These quantities are, for the hot junction:

- Thermal input (Q_H) from an outside heat source.
- Internal input from resistive heating (Q_{Joule}).
- Electrical energy output from thermoelectric effect (P_{TE}).
- Thermal output by conduction (Q_{Cond}) away from the hot junction toward the cold junction.

For the cold junction, the quantities are:

- Thermal output (Q_C) to the cold source.
- Internal input from resistive heating (Q_{Joule}).
- Electrical energy input of thermoelectric power (P_{TE}).
- Thermal input from conduction (Q_{Cond}) from the hot junction.

These requirements are shown in Fig. 3.

As shown in Fig. 3, the TEG model is divided into hot side and cold side. The hot side includes the bottom plate of the heat exchanger, the electrical insulating plate, and the conducting copper strips. The heat transfer rate depends on the thickness and the thermal conductivity of each layer, as well as the convective heat transfer coefficients; these coefficients are between the fluid and the inside surface of the flow channel at the hot and cold sides. Located between the hot and cold

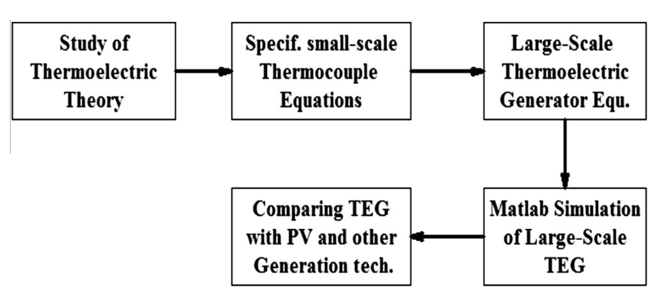

Figure 2 TEG model formulation.

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات