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A Global Design Approach for Large-Scale Thermoelectric Energy Harvesting Systems

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The method described here aims at designing and optimizing a thermoelectric system to maximize the total electrical power produced by a large-scale thermoelectric system with a nonconstant heat source. This method consists of three steps: (i) definition of the thermal and electrical parameters of the thermoelectric generator, (ii) use of a multi-objective optimization method to find the parameter values that maximize the electrical power or the conversion efficiency, and (iii) selection of local operating points for maximum global electrical output. This method shows better performance than other, more intuitive design approaches.

Key words: Large-scale thermoelectric generator, energy harvesting, multi-objective optimization

INTRODUCTION

Sustainable development is one of the current big challenges, also for electrical power production. Besides the development of green energy systems (photovoltaic, wind turbine, geothermal sources, etc.), harvesting waste energy can help to meet this challenge. Particularly, heavy industries such as steel-making, cement production, and glass-making consume huge amounts of energy as heat. A large part of this is currently rejected as low-grade heat due to the absence of a technologically viable and economically acceptable recovery device. A promising technology for low-grade heat harvesting is thermoelectricity, owing to its good reliability, despite its low conversion efficiency.[1–3]

A furnace used for glass-making is an explicit example of a potential low-grade heat harvesting site in heavy industry. The exhaust gas of this kind of furnace has a flow rate of several tens of thousands of m^3 per hour, representing about 10 MW of low-grade heat. Furthermore, the exhaust pipes present surfaces of hundreds of square meters.

As shown in Fig. 1, a large-scale thermoelectric generator (TEG) presents the peculiarity that the hot source constituted by such an exhaust hot gas device presents a decreasing temperature. Indeed, this temperature decreases from the inlet to the outlet. The present study develops a global design approach based on multi-objective optimization that takes this peculiarity into account to maximize the total electrical output power generated by the system. This approach is different from previous studies in which the optimization aimed at maximizing the efficiency, for example, in the case of an automotive exhaust pipe.[4] However, it has been shown that, when the heat source is potentially cost free, it is preferable to improve the power density rather than the conversion efficiency.[5,6] The work of Suzuki and Tanaka followed this guideline for the design of planar and cylindrical large-scale thermoelectric modules under different fluid configurations.[7,8]

In the first part of this paper, the TEG unit cell used in this study is presented together with the properties of the constitutive materials. The second part describes the lumped parameter model used to easily compute the performance of a TEG on the basis of its characteristics. In the third part, a multi-objective optimization procedure based on a

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