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TEG Maximum Power Point Tracking using an Adaptive Duty Cycle Scaling Algorithm

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Abstract

The thermoelectric generator (TEG) is a clean and noiseless renewable electrical power source that requires no moving parts. Unfortunately, the practicality of TEGs is currently limited by its typical low conversion efficiencies. Subsequently, researchers have taken many approaches to improve the efficiency of the TEG. One of such approaches is the utilization of maximum power point tracking (MPPT) techniques. MPPT techniques are popularly used in literature for maximizing the power that is extracted from solar panels. Such techniques can be reused for the TEG scenario because TEGs also have I-V and P-V characteristics that follow the same principles as that of solar panels. This paper presents a "Lock-On Mechanism" MPPT algorithm and applies it specifically to the TEG application. In comparison to conventional fixed step based MPPT algorithms, the proposed algorithm improves the MPP tracking performance by adaptively scaling the DC-DC converter duty cycle whenever the MPP is located. In doing so, the steady state oscillations become negligibly small thus be considered eliminated and a smooth steady state MPP response is achieved. Simulation and experimental results prove that the proposed algorithm is fast and stable in comparison to the conventional fixed step hill climbing algorithm.

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Keywords: PWM, MPPT, SEPIC Converter, TEG

1. Introduction

The thermoelectric generator (TEG) is a semiconductor device which generates electric power via a temperature differential between the ends of the device's thermocouples. The TEG not only has no moving parts, but is also a clean and noiseless renewable energy source. Due to these beneficial merits, the TEG finds many applications such as extracting energy from an automotive heat waste system [1] or the combustion chamber [2].

Unfortunately, the practicality of TEGs is currently limited mainly because of its relatively low conversion efficiency from heat to electricity. As such, researchers have taken various different

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approaches, all of which have the common goal of improving the conversion efficiency of the TEG. For instance, one approach involves the search for better materials to be used as the thermocouple of the device. Such an approach is based on the characterization of the TEG by its figure of merit $ZT = \frac{\alpha\sigma}{\lambda}T$ where a higher Z means a higher TEG performance. State of the art materials used for the TEG thermocouples include bismuth telluride [3, 4], a material with optimized performance at room temperature, lead telluride [5] and skutterudites [6]. Recently, researchers have even found a new class of materials known as nanostructured materials which is found to achieve an even better ZT performance [7, 8].

Alternatively, another approach to achieve better TEG conversion efficiencies is by improving its geometric design. For instance, references [9-11] provided comprehensive mathematical models of the TEG in operation and based on these models, the TEG geometric design can be optimized. The two stage TEG was also proposed in [12] where the TEG mathematical model was modified to include the extra stage. Optimization of the TEG utilizing the genetic algorithm (GA) has also been conducted in [13, 14] although these analyses are focused on thermoelectric cooling systems as opposed to electricity generation. On the other hand, the authors of this paper have previously proposed a GA optimization of the TEG as utilized in a hybrid solar panel/TEG application when used in an outer space environment [15].

The third approach, which is the focus of this paper, is to use the principles of maximum power point tracking (MPPT). Similarly to solar panels, when electrically connected to an external load, TEGs have power characteristic curves where if the impedance of the external load has a particular unique size, maximum power is retrieved. This unique impedance varies considerably with both the design of the TEG and its operating conditions. Subsequently, a maximum power point tracking is utilized to actively emulate the impedance such that the TEG is always operating at the maximum power point (MPP). As the I-V and P-V characteristics of the TEG follow the same principles as that of the solar panel, MPPT techniques that are commonly used for solar panels can be reused for the TEG. For instance, in [1, 16], the perturb and observe (P&O) algorithm was used which simply involves perturbing the input voltage of the DC-DC converter until the MPP is located. Perturbation of the duty cycle directly (which is often known as hill climbing) was also used in [17] for the TEG application. The popularly known incremental conductance technique was also utilized in [18, 19] although in [19], the focus is on a seamless transfer between MPPT and the power matching mode. Nevertheless, the aforementioned MPPT techniques suffer from steady state oscillations around the MPP which results in significant power losses. By recognizing the nature of the TEG equivalent circuit model, a recent study [20] used the fractional short circuit current method to evaluate the MPP. While this method is simple in nature, it requires a periodic disconnection of the load from the TEG in order to measure the short circuit current. Moreover, this method assumes 100% accuracy on the TEG circuit model which, in reality, is often not the case.

This paper proposes an algorithm that adaptively scales the DC-DC converter duty cycle such that steady state oscillations around the MPP are so small that they can be considered eliminated. The proposed algorithm will be demonstrated through simulations and a hardware experiment of the TEG with a large temperature differential between its two end surfaces. The resulting performance will be compared to that of the fixed step counterpart. Despite the simplicity and the minimal computational intensity, the proposed algorithm achieves a very fast and stable tracking response regardless of the applied conditions on the TEG.

The remainder of this paper is organized as follows. Section 2 describes the equivalent circuit model of the TEG which is a prerequisite for the subsequent sections. Section 3 provides the full details of the proposed algorithm. Section 4 describes the simulation parameters and Section 5 presents the simulation