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Thermoelectric Power Generator Design for Maximum Power: It's All About *ZT*

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There is a significant amount of literature that discusses thermoelectric power generator (TEG) design, but much of it overly simplifies the design space and therefore the results have limited use in designing real-life systems. This paper develops a more comprehensive model of the thermal and electrical interactions of a TEG in a system with known hot-side and cold-side thermal resistances and corresponding constant system temperature differential. Two design scenarios are investigated for common TEG system applications. In one method, the power from a TEG is maximized for a given electrical load, simulating a case where the TEG is electrically in series with a known load such as a fan. In the second design scenario, the power from a TEG is maximized for a given electrical load resistance ratio, n (the ratio between the external load resistance and the internal TEG resistance), simulating an application where the TEG is electrically in series with a load-matching converter. An interesting conclusion from this work is that, in the first design scenario, the electrical load resistance ratio, n, that maximizes TEG power occurs at $\sqrt{1+ZT}$ (where ZT is the thermoelectric figure of merit) instead of 1 as reported previously in literature. Equally interesting is that, if you define an analogous thermal resistance ratio, m' (representing the ratio between the TEG thermal resistance at open-circuit conditions and the system thermal resistance), the maximum power in both design scenarios occurs at $\sqrt{1+ZT}$ instead of the commonly cited value of 1. Furthermore, results are presented for real-life designs that incorporate electrical and thermal losses common to realistic TEG systems such as electrical contact resistance and thermal bypass around the TEG due to sealing.

Key words: Thermoelectric device, maximum power, optimal design

INTRODUCTION

Designing an optimal thermoelectric generator (TEG) in a system with thermal resistance (heat sinks) on either side of the TEG is common in many applications. In some of these applications, the TEG is wired in series with a known fixed electrical load such as a fan, whereas in other applications, the TEG is wired in series with an electrical load that can maintain the ratio between the load and internal resistance of the TEG, such as a load-matching converter. In both cases, the design of the TEG [the geometry of the individual thermoelectric (TE) elements and the number of these elements] can be found by optimizing the TEG power.

A typical TEG system is shown in Fig. 1 and includes heat sinks on the hot side and cold side of the TEG with defined thermal resistance of HSR and CSR, respectively. The heat source is at T_{Source} and the heat sink is at T_{Amb} temperatures. Heat flows from T_{Source} through the heat sink and TEG to T_{Amb}. If there is a thermal bypass around the TEG, then heat also flows in parallel with C_{Loss}. The temperatures across the TEG are T_{H} and T_{C}, respectively. The TEG is wired electrically in series with an electric load R_{Load}. The TEG is made of N number of couples with length-to-area ratio of λ (Table I).

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