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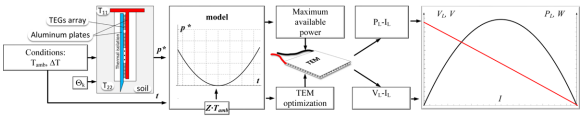

Harnessing Surface and Subsurface Soil Temperature Gradients within a One-Meter Depth for Energy Harvesting in Wireless Sensor Network Nodes

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Wireless sensor networks (WSNs) are rapidly gaining popularity due to their widespread use in environmental monitoring, industrial automation, and smart cities[1]. However, these networks' nodes are typically powered by batteries, which poses significant limitations. Most batteries must be replaced periodically, which is labor-intensive, expensive, and environmentally unfriendly, mainly when networks consist of thousands of nodes spread over vast and often inaccessible areas. This drives the need for off-grid power solutions.

This study proposes to explore the potential of using thermoelectric low-power electrical harvesting. The root mean square temperature gradient between the soil surface and shallow depths reaches an average of 2 to 5 degrees Celsius, enabling harvesting[3][4]. The proposed system aims to provide continuous power to WSN nodes, eliminating the need for batteries.

The present research includes developing an analytical model of the proposed topology of a thermoelectric harvester for ultra-low temperature gradients. Dimensional analysis of the model [2] allows us to theoretically estimate the harvester's maximum power in steady-state mode under known environmental conditions and thermal path, select an array of thermoelectric modules optimally, and calculate the electrical load at which the power will be maximum.

We built a laboratory prototype of the harvester, consisting of an array of thermoelectric modules sandwiched between long insulated aluminum plates that serve as a thermal path. The harvester is equipped with controlled temperature sources that simulate temperature gradients between soil layers. Using the prototype, we confirmed the model's operability.

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