


Editorial

# Advance Energy Harvesting Technologies

Dibin Zhu 

School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; d.zhu@sjtu.edu.cn

Energy harvesting is the conversion of unused or wasted energy in the ambient environment into useful electrical energy. It can be used to power small electronic systems such as wireless sensors and is beginning to enable the widespread and maintenance-free deployment of Internet of Things (IoT) technology. This Special Issue is a collection of the latest developments in both fundamental research and system level integration.

This Special Issue features two review papers covering two of the hottest research topics in the area of energy harvesting: 3D printed energy harvesting and triboelectric nanogenerators (TEGs).

The fast-evolving 3D printing technology has enabled researchers to manufacture energy harvesting devices in a simple and expedient way. Gawron et al. [1] provide a comprehensive review of the development of hybrid and non-hybrid 3D printed electromagnetic vibration energy harvesters. Various harvesting approaches, their utilized geometry, functional principle, power output and the applied printing processes are discussed. This Special Issue analyzes the advantages and challenges of 3D printed harvesters and identifies research gaps in the field.

On the other hand, TEGs are recognized as one of the most promising solutions for future energy harvesting. In the review by Nazar et al. [2], TEGs targeting various environmental energy resources are systematically summarized, including various TEGs for ocean and other applications as well as the hybridization of TEGs with other energy harvesters to improve performance. The advantages and disadvantages of various TENG structures are explored. A high-level overview in this Special Issue explores the connection of TENGs with structural health monitoring, artificial intelligence and highlights the future developments of this technology. This is a must-read paper for those who are interested in TENGs.

In addition to these two review papers, this Special Issue also includes ten research papers covering a wide range of energy harvesting techniques, including electromagnetic and piezoelectric wideband vibration, wind, current-carrying conductors, thermoelectric and solar energy harvesting, etc. Not only are the foundations of these novel energy harvesting techniques investigated, but the numerical models, power conditioning circuitry and real-world applications of these novel energy harvesting techniques are also presented.

Bradai et al. [3] study a novel energy-autonomous wireless sensor system powered by a wideband electromagnetic energy harvester via passive energy management. The self-powered sensor system can detect machine failure and deliver alerts without the use of an external energy supply. The solution can also detect failure without the use of additional sensors by utilizing the Analog Digital Converters (ADCs) of the Wireless Sensor Nodes (WSNs) themselves, making it more compact with lower energy consumption.

A dual-resonance vibration electromagnetic energy harvester (EMEH) for wideband operation is proposed by Feng et al. [4]. Compared with the conventional dual resonance harvester, the proposed system realizes an enhanced “band-pass” harvesting characteristic with a significant improvement in the average harvested power. Furthermore, two resonant frequencies are decoupled in the proposed system, which leads to a more straightforward design. Experimentally, the proposed dual resonance EMEH has demonstrated a higher



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Normalised Power Density over a wider frequency range twice that of the state-of-the-art wideband EMEHs.

Bäumker et al. [5] introduce a novel animal-tracking system powered solely by thermal energy harvesting. The proposed tracker harvests electrical power using the temperature difference between the animal's fur and the environment. The steps to enhance power generation are presented and validated in a field test using a system which fulfils common tracking tasks, including GPS, activity and temperature measurements, and wireless data transmission via LoRaWAN. Furthermore, the ultra-low-power design has extremely low overall sleep power consumption and can operate when temperature differences are minimal.

A novel approach is presented by Khan et al. [6] to harness energy from a small-scale wind turbine to support communication primitives in electric vehicles, enabling a variety of applications in the Internet of Vehicles (IoV). The harvested power is processed through regulation circuitry to achieve the desired power supply for the end loads, such as the battery and supercapacitor. The orientation for optimum conversion efficiency is proposed through an ANSYS-based aerodynamics analysis and verified in experiments.

Russo et al. present the dynamic experimental identification of an inductive energy harvester for the conversion of vibration energy into electric power [7]. The proposed energy harvesting technique is based on an asymmetrical magnetic suspension and addresses structural monitoring applications on vehicles. The design of the interfaces for the electrically, magnetically, and structurally coupled systems forming the harvester are described using dynamic modelling and simulation. The experimental results are also compared with the harvester's dynamic response, calculated via numerical simulations; good correspondence was obtained.

Liu et al. [8] validate the potential of unequal-length section-varied geometries in developing an orthoplanar spring-based piezoelectric vibration energy harvester (PVEH). A basic quad-trapezoidal-leg orthoplanar spring (QTOPS) is theoretically analyzed, and the structurally effective stress and eigenfrequency are formulated to determine the main dimensions. An improved QTOPS with additional intermediations is also constructed and simulated. It is experimentally verified that the proposed approach is more suitable to construct a high-performance PVEH than the orthoplanar spring with equal-length or rectangular legs.

Sun et al. [9] introduce a new method of electricity generation using a Wiegand sensor. The design and verification of a self-oscillating boost converter circuit are presented in this paper. A DC voltage obtained by rectifying and smoothing the pulse voltage generated from the Wiegand sensor is boosted by the proposed circuit. A quantitative analysis of the power generated by the Wiegand sensor reveals a suitable voltage-current range for application in self-powered devices and battery-less modules.

In the work by Jiang et al. [10], the acoustic resonance of a circular pipe and an equivalent diameter square pipe are simulated with the realizable  $k-\epsilon$  DDES model. The influences of the intersecting line of the pipe on the acoustic resonance are discussed. Furthermore, the influence of the branch angle on acoustic resonance is also studied. The simulation results identified methods to improve output power of the mean flow wind harvesting and suppress acoustic resonance in industrial pipelines.

Dai et al. [11] review the existing applications of PV facilities in road structures and facilities, including two systematic large-scale applications in China where the PV facilities are applied in spare spaces without traffic loads. The existing practices of PV facilities in pavement structures with vehicle loads are also presented and discussed. In addition, a novel integration of amorphous silicon (a-Si) PV cells and glass-fiber-reinforced polymer (GFRP) profiles is proposed. The existing mechanical experiments on the a-Si PV cells and their integrations with GFRP profiles are introduced and their mechanical performance is evaluated experimentally.

The study by Han et al. [12] focuses on metallic submicron-sized silicon particles used to improve the absorption properties of absorber plates for solar still applications. Various

concentrations of silicon are mixed with black paint and applied to the aluminum plate. Indoor and outdoor testing are conducted using an improvised apparatus for concentration optimization. Although this research is not directly linked to traditional energy harvesting technologies, it does provide a unique insight into an important application of solar energy.

As the Guest Editor of this Special Issue, I hope that readers will find the papers intriguing and that this collection can stimulate the research community to further advance this important research area in the years to come. Finally, I would like to thank all the authors, reviewers and editorial staff who have contributed to this Special Issue.

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