Guest Editorial

ENERGY HARVESTING from ambient energy resources is emerging as a potential solution to the scant and expensive conventional oil and gas resources. While renewable energy sources such as solar, wind, and ocean are promising in providing large power for grid-connected and stand-alone applications, human power and vibration-based energy harvesting are being considered to power low-power electronic devices due to their advantages in terms of availability, requiring no chemical fuels, low environmental impact, lower costs, higher efficiencies, and having little heat signature. The widespread adaptation of portable electronic devices has led to a dramatic increase in energy consumption over the past two decades. Therefore, it is imperative to develop structures and power electronic interfaces to harvest a useful amount of energy to power these devices and improve the overall efficiency of the system. The main objective of this special section is to bring the ideas of the worldwide research community into a common platform, to present the latest advances and developments in the design, mathematical modeling, optimization, power electronic control, and practical implementation of energy harvesting from various environmental energy sources.

We received a total of 24 submissions for this Special Section on Energy Harvesting of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS. All of the submitted manuscripts were of exceptionally high quality. Unfortunately, we have been able to accept only some of these manuscripts, published in this Special Section due to space limitations. The first paper by Rocha *et al.* from the University of Minho, Portugal, demonstrates the use of piezoelectric polymers to harvest energy from human motion. Electroactive β–PVDF has been utilized as an energy-harvesting element in a bicolor sole prepared by injection, together with the electronics which are required to increase energy transfer and storage efficiency. The fabrication of a shoe that is capable of generating and accumulating the energy has been presented. It has been concluded that, in order to extract suitable energy for the operation of electronic appliances, material enhancement to improve electromechanical conversion and optimize the energy transfer is essential.

In the second paper by Mehraeen *et al.* from Missouri University of Science and Technology, a new voltage compensation scheme is introduced. This scheme, when applied to the voltage inversion method (also known as SSHI), provides more than 14% increase in the harvested power in comparison to the parallel inversion method (parallel SSHI) and more than 50% in the case of the series inversion method (series SSHI). A field test of the proposed tapered beam by using a dozer for earthmoving applications is carried out, and the results are presented. The demonstrated tests stipulate that the scavenger generates 5 mW of energy. It has been concluded that the beam should be designed to harvest energy from multiple vibration frequencies as opposed to a single frequency in order to increase the efficiency of the system.

The third paper by Liu *et al.* from The University of Hong Kong presents a novel stand-alone wind/photovoltaic (PV) hybrid generation system for remote and isolated areas. In this proposed hybrid system, wind power and PV power inherently complement each other to a certain extent, which results in facilitating continuous output power. An innovative doubly excited permanent-magnet brushless machine is utilized to harness the maximum wind power via online flux control. A single-ended primary inductance converter is used to extract the maximum solar power. The experimental results are presented to validate the feasibility of the proposed system to provide high efficiency.

The fourth manuscript by Tabesh and Fréchette from the University of Toronto proposes an adaptive efficient energy-harvesting circuit at low power ranges above 0.5 mW. The circuit, which is useful for efficient ac/dc voltage conversion of a piezoelectric micropower generator, maximizes the extracted power from a vibrating piezoelectric element, independent of the load and piezoelectric parameters. The controller of the proposed topology consists of only one chip with a single supply voltage. Due to its low power consumption of the control unit, it can readily operate as a stand-alone subsystem. The experimental verifications of the circuit show that the nonscalable power dissipations of the controller unit are less than 0.05 mW, and the efficiency of the circuit is about 60% for output powers between 0.5 and 5 mW.

The fifth paper by Khaligh *et al.* from Illinois Institute of Technology presents the state-of-the-art progresses in kinetic energy harvesting for applications ranging from implanted devices and wearable electronic devices to mobile electronics and self-powered wireless network nodes. The advances in the energy harvester adopting piezoelectric and electromagnetic transduction mechanisms are presented. The existent kinetic piezoelectric generators, including human-powered and vibration-based devices, are comprehensively addressed. In addition, the electromagnetic generators are reviewed, which include resonant, rotational, and hybrid devices. In the conclusion part of the manuscript, the comparison between the transduction methods and future application trends is presented.

The sixth paper by Carmo *et al.* from the University of Minho demonstrates a microenergy generation approach by using the temperature differences through Seebeck principle. A thermoelectric microconverter for energy-scavenging systems to supply low-power electronics was fabricated using thin films of bismuth and antimony tellurides. Thin films of n-type bismuth and p-type antimony tellurides were obtained by thermal coevaporation. The films were patterned by photolithography and wet-etching techniques. Target applications for this

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thermoelectric microconverter include a wireless electroencephalogram and generating electrical energy from the exhaust gas system of a car's combustion engine. It has been concluded that the thermoelectric microdevices with high figures of merit, based on superlattices, are the key to generate power from low temperature gradients.

The last paper by Li *et al.* from Ryerson University presents a novel cantilever piezoelectric power harvester with a curved L-shaped proof mass. This structure leads to lower fundamental frequency and higher power density. At an input acceleration of $0.75g$, the proposed structure produces an average power of 350 μW with a power density of 1.45 mW/cm^3, which is 68% higher than that of the conventional block-shaped mass harvester. It has been shown that this structure generates an average power of 49 μW at 3.0-mi/h walking speed.

We hope that this Special Section becomes an enticement for instigating new research in the area of energy harvesting and inspires new engineers to work in the area of energy-storage systems. We would like to thank Prof. B. M. Wilamowski, the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS Editor-in-Chief, from the Alabama Microelectronics Science and Technology Center, Auburn University, for his support. We are also grateful to our reviewers who dedicated their time in reviewing the submitted papers and provided many good suggestions to the authors.

ALIREZA KHALIGH, *Guest Editor*
Energy Harvesting and Renewable Energies Laboratory
Electric Power and Power Electronics Center
Department of Electrical and Computer Engineering
Illinois Institute of Technology
Chicago, IL 60616 USA

PATRICK LYLE CHAPMAN, *Guest Editor*
Department of Electrical and Computer Engineering
University of Illinois at Urbana–Champaign
Urbana, IL 61801-2918 USA

REZA GHODSSI, *Guest Editor*
Institute for Systems Research,
Department of Electrical and Computer Engineering
University of Maryland
College Park, MD 20742 USA

Alireza Khaligh (S'04–M'06–SM'09) received the B.S. and M.S. degrees (with highest distinction) in electrical engineering from Sharif University of Technology (SUT), Tehran, Iran, and the Ph.D. degree in electrical engineering from Illinois Institute of Technology (IIT), Chicago.

He was a Postdoctoral Research Associate in the Department of Electrical and Computer Engineering, University of Illinois at Urbana–Champaign, Urbana. He is currently the Director of the Energy Harvesting and Renewable Energies Laboratory, Electric Power and Power Electronics Center, Department of Electrical and Computer Engineering, IIT, where he has established courses and curriculum in the area of energy harvesting and renewable energy sources. He is the principle author/coauthor of over 65 journal and conference papers, as well as three books, including *Energy Harvesting: Solar, Wind, and Ocean Energy Conversion Systems* (CRC Press, 2009), *Energy Sources, Elsevier Power Electronics Handbook* (Elsevier, 2009), and *Integrated Power Electronics Converters and Digital Control* (CRC Press, 2009). His major research interests include modeling, analysis, design, and control of power electronic converters, hybrid electric and plug-in hybrid electric vehicles, energy scavenging/harvesting from environmental sources, and the design of energy-efficient power supplies for battery-powered portable applications.

Dr. Khaligh was the recipient of the Distinguished Undergraduate Student Award at SUT presented jointly by the Minister of Science, Research and Technology and the President of SUT. He was also the recipient of the 2009 Armour College of Engineering Excellence in Teaching Award from IIT. He is a member of the Vehicle Power and Propulsion Committee, IEEE Vehicular Technology Society, the IEEE Power Electronics Society, the IEEE Industrial Electronics Society, the IEEE Education Society, and the Society of Automotive Engineers. He is the Conference Chair of the IEEE Chicago Section. He is an Associate Editor of the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY. He was a Guest Editor for the Special Issue of the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY on Vehicular Energy Storage Systems.

Patrick Lyle Chapman (S'94–M'00–SM'05) received the B.S. and M.S. degrees in electrical engineering from the University of Missouri, Rolla, in 1996 and 1997, respectively, and the Ph.D. degree from Purdue University, West Lafayette, IN, in 2000.

He is currently the Grainger Associate and an Associate Professor at the University of Illinois at Urbana–Champaign, Urbana, and the Cofounder and the Chief Technology Officer of SmartSpark Energy Systems, Inc., Champaign, IL. His research interests within power electronics include applications to integrated designs, renewable energy, electromechanics, automated modeling, hybrid energy systems, and energy harvesting.

Dr. Chapman is an Editor for the IEEE TRANSACTIONS ON ENERGY CONVERSION and a Historian for the IEEE Power Electronics Society (PELS). He is a Member-at-Large of the IEEE PELS Administrative Committee and was the Assistant Program Chair for the 2009 IEEE Applied Power Electronics Conference. He was the recipient of the National Science Foundation CAREER Award and the Office of Naval Research Young Investigator Award. He was named the Richard M. Bass Outstanding Young Power Electronics Engineer in 2006.

Reza Ghodssi (M'96) received the B.S., M.S., and Ph.D. degrees from the University of Winsconsin-Madison, all in electrical engineering.

He is currently with the Department of Electrical and Computer Engineering, University of Maryland (UMD), College Park, where he is the Herbert Rabin Distinguished Professor and the Director of the Institute for Systems Research and the Director of the MEMS Sensors and Actuators Laboratory. He is also with the Fischell Department of Bioengineering, the Maryland NanoCenter, the UMD Energy Research Center, and the Department of Materials Science and Engineering, all at UMD. At UMD, his research group has pioneered the development of next-generation PowerMEMS devices supported on microball-bearing MEMS-based gray-scale technologies and the use of novel III–V optical MEMS devices and systems for chemical and biological detection. At the University of Wisconsin, Madison, his Ph.D. thesis was focused on the development of a high-aspect-ratio microfabrication process for an electrostatic-driven MEMS device using X-ray lithography and LIGA technology. At Massachusetts Institute of Technology, Cambridge, he developed the building block MEMS fabrication technologies for a microturbine generator device and also served as an Assistant Director on that project. His research has been funded by the Army Research Laboratory, the Department of Energy, the National Science Foundation (NSF), the Laboratory for Physical Sciences, the NASA Goddard Space Flight Center, the National Institute of Standards and Technology, and the R.W. Deutsch Foundation. He has authored or coauthored over 70 scholarly publications. His research interests are in the design and development of microfabrication technologies and their applications to micro-/nanodevices and systems for chemical and biological sensing, small-scale energy conversion, and harvesting.

Dr. Ghodssi was the Chair of the 9th International Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, which is also known as "PowerMEMS 2009." He has served as the Program Cochairman for the 2001 International Semiconductor Device Research Symposium and as the Chairman of the "MEMS and NEMS Technical Group" of the American Vacuum Society (AVS), from 2002 to 2004. He is a Coeditor of the *Handbook of MEMS Materials and Processes* (Springer, 2009) and is an Associate Editor of the *Journal of Microelectromechanical Systems* and the *Journal of Biomedical Microdevices*. He was the recipient of the 2001 UMD George Corcoran Award, the 2002 NSF CAREER Award, and the 2003 UMD Outstanding Systems Engineering Faculty Award. He was among 100 of the nation's outstanding engineers invited to attend the National Academy of Engineering U.S. Frontiers of Engineering Symposium in 2007. He is the Cofounder of the MEMS Alliance in the greater Washington area and a member of AVS, the Materials Research Society, the American Society for Engineering Education, and the American Association for the Advancement of Science.