Novel vibrational and solar energy harvesters

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Instrumental vibrations and IR light are converted to electricity, in a possible solution for small- and large-scale energy needs.

Electrical energy currently comes primarily from fossil fuel combustion and nuclear fission. These energy sources are neither renewable nor suited to small-scale devices. Most important, electrical generators typically do not make use of all energy output, e.g., IR light in the case of solar cells. Energy harvesting aims to address these limitations by making use of background (unused) energy. While the original concept of employing unused energy dates back centuries, vibrational and solar energy harvesting are largely emerging technologies. For example, kinetic energy harvesters employ vibrational energy—commonly electrostatic, electromagnetic, or piezoelectric (the translation of mechanical stress into electricity)—to power small devices, such as a vibrational sensor to control grip forces exerted by a prosthetic hand and a small-scale wind power generator.

With the goal of fabricating commercial energy harvesting technologies, we are conducting long-term applied research in vibrational and solar energy harvesting. An example is our microgenerator (see Figure 1), which is based on fundamental scientific principles. Vibrational energy (generated in the environment, e.g., by passing trucks) moves the magnetic core of the microgenerator, and a converter transforms the resulting voltage into electricity for further processing. High microgenerator efficiency is based on operation in an acceptable resonance band (between 17 and 34Hz). When outside vibrations fall within this range, the generator is able to produce power. Our device is optimized to yield a power output of 20mW. Figures 2 and 3 present its root mean square potential energy, power output, and root mean square current as a function of amplitude and vibration frequency, respectively.

An especially interesting focus of energy harvesting is solar energy. Approximately 4–8% of solar energy (that which is emitted directly from the sun) falls within the visible wavelength range, while much of the remainder is within the IR. Optimizing solar energy harvesters to collect this vast unused energy promises to greatly improve solar cell efficiency. We designed a solar energy harvesting unit and optimized it to collect IR wavelengths and convert them to electrical energy. Its efficiency can be adjusted according to local conditions, e.g., the average number of days in a year that are, say, cloudy or sunny, and the positioning of solar collector systems relative to the equator. If 26–40% of total solar energy is in the IR range, expected typical solar cell energy conversion efficiency ranges from 40–90%, and maximum solar energy usage is 36%. In contrast, using only visible light results in a maximum 1.76% conversion efficiency, assuming a typical photovoltaic efficiency of 13–22%. Our solar

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energy unit is currently undergoing verification and optimization for final material design.

The device is based on a system in resonance mode. It enters the resonance state upon collision with an electromagnetic wave. The basic collector cell currently measures 9×3μm and is tuned to a middle wavelength of 3000nm. Special electronics (power management) controlling the operating load enable us to manage power consumption and to maintain operation in an optimum mode. A schematic of the circuit is shown in Figure 4. The unit indicated as Emg_sou is an element that transforms the incoming electromagnetic wave into one that enters the resonant circuit (C-L) formed by a capacitive and inductive component. This element is situated in resonance for the wavelength of the incoming electromagnetic wave. The nonlinear element D and capacitor C_f smooth the electrical component of the field, allowing it to enter the electronic power management system. At any output impedance, it provides electrical loading to the resonant circuit such that operation remains within an acceptable resonance limit. For our solar energy harvester, the resonance behavior of the circuit is ideally of a low-quality factor, such as when the change in frequency is approximately between 0.8 and 1.0.

In summary, energy conversion from one form to another, leaving a minimum of unused energy, is a possible solution for future energy needs. Future applications of this principle, under development in our laboratory, are suited both to small devices and large industrial units.

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Pavel Fiala started research in Brno in 1988. He joined the Department of Theoretical and Experimental Electrical Engineering (DTEE) in 1990, and became director of the laboratory for modeling and optimization inside electromechanical systems in 1993. He received his PhD in 1999, and became head of the DTEE in 2003. He is currently an associate professor.

References