Chapter 5
Rainfall Energy Harvester

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ABSTRACT
This chapter provides a detailed study on the harvest of the energy contained in raindrops by means of piezoelectric transducers. The energy harvester has the role of an electric source, able to recharge storage devices of small electronic components, such wireless sensors, by using the vibrational energy released by the drops hitting the transducer, reducing in such a way the chemical waste of conventional batteries. In technical literature, diverse studies agree on the level of suitable generated voltage on the electrodes of a piezoelectric transducer subjected to rainfall, but a complete characterization on the supplied power is still missing. This work, also to limit optimistic forecasts, takes into account the behavior of the transducers in different scenarios: subjected to real and artificial rainfall, standalone or in parallel configuration, in conventional geometries, due to the commercial format or in customized shape, free to move or with an imposed optimal deflection.

INTRODUCTION
In recent years an increasing attention in generating energy from the ambient vibrations, leads the study on the employment of smart materials. Low power consuming electronic devices, devoted to the wireless monitoring application, can be fed by the conversion of mechanical energy, otherwise wasted, into useful electric energy. The use of piezoelectric transduction mechanism over other electromagnetic and electrostatic alternatives seems to be one of the best strategy to ensure the requirements for the achievement of an amount of power and a reduced environmental impact. Piezoelectric materials have a lack of symmetry in the crystal lattice, which generates a dipole moment, function also of the stress acting on the structure. The lattice structure allows the fabrication of device both in macro and micro scale, thus

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surpassing the limitations due to the number of windings to be used in the electromagnetic transducers. In this perspective at each point of interest in which a sensor must be placed, the kinetic energy of the ambient vibrations, energy normally wasted in environment without a useful purpose, can be coupled to the electromechanical transducer, which feeds electronic monitor apparatus. The vibration energy can be regarded as marginal energy, an energy of small entity, usable for utilities of reduced energy capacity, such as the transmission of information following the collection of the same by appropriate sensors.

A complete overview on the possibility of harvest energy and collect informations in different scenarios is difficult to be provided, since novel approaches and innovative idea are continually being developed: Benasciutti and Moro (2010) studied the possibility of harvest energy from vibrating shoe-mounted piezoelectric cantilevers, such system can also be used to monitor weight distribution on the sole of the foot; Xiang, Wang, Shi and Zhang (2013) faced the harvesting of energy induced from the deformation of pavements due to moving vehicles; but also van den Ende, van de Wiel, Groen and van der Zwaag (2012) discussed the harvesting from automotive tires; and finally Hobeck and Inman (2012) proposed an innovative piezoelectric grass energy harvester.

Also the rainfall energy harvest has been faced by Jager, Guigon, Chaillout and Despesse (2008). The idea is to convert, by means of piezoelectric plates, the kinetic energy possessed by the drops of rainwater into electrical energy. A pioneering comparison of different piezoelectric materials, in order to investigate the possibility of energy generation water droplets energy sources for low power electronic devices, has been studied by Vatansever, Hadimani, Shah and Siores (2011) These studies confirm that the single drop of water hitting the piezoelectric plates generates voltages less than a dozen of volts (peak to peak), but no evaluation on power has been proposed. The drops of rain strike the piezoelectric material in a cantilever configuration, which may be subject to study to improve the energy produced as described by Benasciutti, Moro, Zelenika, and Brusa (2010) and again by Benasciutti, Moro, and Gallina (2013). Although the voltage peak to peak, produced by droplets, seems high enough to interact with electronic devices or rectifiers a more accurate characterization is required, in order to dispel excessive optimistic predictions. The concept of energy flow, presented by Liang and Liaoin (2011) and by Erturk and Inman (2011), clarifies the dissipation of energy during the harvesting process, in order to separate the electromechanical coupling coefficient of the system, natural frequencies, damping ratio and electric load. Useful schemes to model the electromechanical coupling have been proposed by Roundy and Wright (2004) and validated here for the raindrop harvester.

Objective of the chapter is to study the amount of power harvested from the rain, since such characterization is still missing. To better define the amount of power extracted from a single drop of rain, are compared different systems, consisting of commercial transducers, which are exposed to natural and artificial rain, and also are subject to suitable configurations, which differ in shape, for the fixing of the edges, for the deflection, in order to increase the extracted power.

PIEZOELECTRIC TRANSDUCERS AND RAINDROP

Piezoelectricity is a form of coupling between electrical and mechanical behaviors present in many materials: the generation of an electric charge in certain non-conducting materials, such as quartz crystals and ceramics, when they are subjected to mechanical stress (such as pressure or vibration) is known as direct piezoelectric effect, whereas the generation of vibrations in such materials when they are subjected to an electric field is the converse (inverse) effect.
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