



Report on
Energy

Draft Version

Term 1/2008

Authors: Odile BERTOLDI, Sébastien BERGER

Version: 06.08.2009

5 Energy

5.7 Energy harvesting

5.7.1 Definition

An energy harvesting (also called energy scavenging or power harvesting) device generates electric energy from its surrounding (vibrations, noise, radiation...) using method of Direct Energy Conversion techniques¹. This means that those kinds of devices do not consume fuel or substance.

5.7.1.1 Small scale

Energy harvesting at small scale include devices which size in less than micro scale.

Two criteria can be taken into account to classify those devices: the origin of the energy to convert and the type of energy converted.²

On one hand, human energy devices get their energy from the user of the electronic appliance (human or animal). The type of energy converted can then be kinetic (produced by a deliberate action or by a casual movement) or thermal.

On the other hand, environment energy devices get their energy from the environment. The type of energy converted can be kinetic (vibrations), radiative (solar or RF) or thermal.

5.7.1.2 Large scale

Energy harvesting at large scale includes energy production sources that have not been treated in previous chapters and which derive from natural phenomena. Therefore, it will be discussed of wind, hydroelectricity, tidal, geothermal.

5.7.2 Short description

5.7.2.1 Small scale

5.7.2.1.1 Kinetic energy harvesting

The genera principle of the kinetic energy harvesting is to use the displacement of a moving part or the mechanical deformation of some structure to produce an electric energy. Three types of devices are available: piezoelectric material, electrostatic energy, magnetic induction.

5.7.2.1.2 Piezoelectric generator

The principle of piezoelectric materials is that under mechanical strain, they suffered an electrical polarization proportional to the applied strain. The piezoelectric effect is used for mechanical to electrical energy conversion. Thus, to generate an electrical energy, piezoelectric materials can be excited by compression, slap or bending.

5.7.2.1.3 Electrostatic energy generator

The principle of electrostatic generators is that an electrical energy is generated when the moving part of a transducer moves against an electrical field.

As an example, the use of a variable capacitor can be cited³. Supposing that vibrations increase the distance between the plates of a capacitor, its capacitance decreases while its charge is maintained constant. The voltage will then increase.

5.7.2.1.4 Magnetic induction generator

The principle of magnetic generators is based on Faraday's law: the variation in magnetic flux through an electric circuit creates an electric field. Two possible solutions can cause the flux variation: the use of a moving magnet whose flux is linked with a fixed coil or of a fix magnet whose flux is linked to a moving coil. The first solution is preferred to the second one. As the relevant parameter here is the magnetic flux through a circuit, the size of the coil is inversely related to the obtained electric field and therefore, to the generated energy.

In application, a vibration creates the displacement of an oscillating mass which is converted into electrical energy by the magnetic induction generator.

5.7.2.1.5 Electromagnetic radiation harvesting

5.7.2.1.5.1 Solar Energy

The solar energy harvesting is also called photovoltaic and has been detailed in another chapter.

5.7.2.1.5.2 RF radiation

The principle is to convert radio waves or microwaves into AC or DC power thanks to an antenna combined with a rectifier. It is for example used to power ID cards or RFID transponders.

5.7.2.1.5.3 Thermal energy

A device that use a change of temperature to produce electrical energy can also be called thermoelectric generators, these thermal energy harvesting devices have been detailed in another chapter.

5.7.2.2 Large scale

5.7.2.2.1 Wind resources

Wind power is the conversion of wind energy into a useful form, such as electricity, using wind turbines.

The principle is quite simple: the energy in the wind turns two or three propeller-like blades around a rotor. The rotor is connected to the main shaft, which spins a generator to create electricity⁴. Conventional horizontal axis turbines can be divided into three components, shown on the following figure:

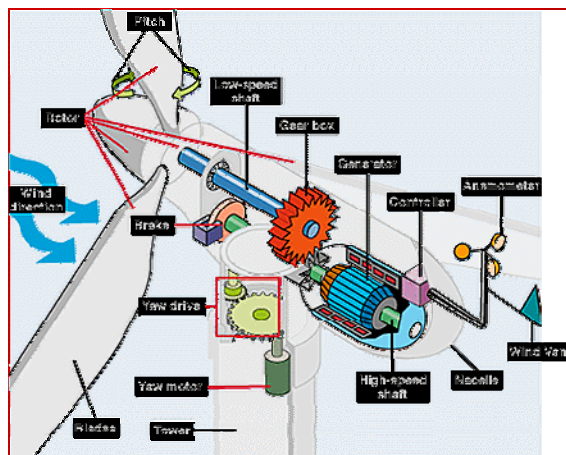


Figure 1: Inside the Wind Turbine

- The rotor component, which is approximately 20% of the wind turbine cost, includes the blades for converting wind energy to low speed rotational energy.
- The generator component, which is approximately 34% of the wind turbine cost, includes the electrical generator, the control electronics, and most likely a gearbox component for converting the low speed incoming rotation to high speed rotation suitable for generating electricity.
- The structural support component, which is approximately 15% of the wind turbine cost, includes the tower and rotor yaw mechanism. The following figure describes the inside of a wind turbine.

At the end of 2008, the worldwide capacity of wind-powered generators was 121.2 gigawatts⁵. The wind production is only about 1.5% of worldwide electricity use, but it is growing rapidly: it has doubled between 2005 and 2008. In several countries it has achieved relatively high levels, representing around 19% of electricity production in Denmark, 10% in Spain and Portugal, and 7% in Germany and the Republic of Ireland in 2008.

5.7.2.2.2 Hydroelectricity

Hydroelectricity or hydropower describes the production of electricity thanks to a water flux.

The energy extracted depends on the volume and on the difference on heights between the source and the water's outflow. In combination with pumped storage, the production of electricity can be easily regulated to follow variations in power demand. During low electrical demand, the excess electricity produced is used to pump

5.7.2.2.3 Tidal resources

Tidal energy (or tidal power), is a form of hydropower that converts the energy of tides into electricity or other useful forms of power. Although it is not yet widely used, tidal power has potential for future electricity generation, especially because tides are more predictable than wind energy and solar power. It indeed derives directly from the relative motions of the Earth–Moon system and to a lesser extent from the Earth–Sun

system. The level of tidal energy generation depends on the water level height of the tide or on the tidal current velocities.

Tidal power can be classified into two main types:

- Tidal stream systems use the kinetic energy of moving water to power turbines (like moving air power windmills). This method is gaining in popularity because of the lower cost and lower ecological impact compared to barrages
- Barrages use the potential energy in the difference in height (or head) between high and low tides. Barrages are essentially dams across the full width of a tidal estuary, and suffer from very high civil infrastructure costs, a worldwide shortage of viable sites, and environmental issues.

5.7.2.2.4 Geothermal resources

Geothermal or heat from the Earth energy can be and already is accessed by drilling water or steam wells in a process similar to drilling for oil. Geothermal energy is an enormous, underused heat and power resource, clean as it emits little or no greenhouse gases, reliable as the average system availability is of 95%, and homegrown as it makes countries less dependent on foreign oil.

Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that drive turbines that drive electricity generators. Three types of power plants are operating today⁶:

- Dry steam plants, which directly use geothermal steam to turn turbines;
- Flash steam plants, which pull deep, high-pressure hot water into lower-pressure tanks and use the resulting flashed steam to drive turbines;
- Binary-cycle plants, which pass moderately hot geothermal water by a secondary fluid with a much lower boiling point than water. This causes the secondary fluid to flash to vapour, which then drives the turbines.

5.7.3 State of R&D

5.7.3.1 Small scale

Few works have been conducted implicating the use of nanotechnology or nanoscience in the field of the previous energy harvesting systems. Considering the work principle of the considered systems, the works turn more on the reduction of the devices size than on the improvement of the material characteristics.

The problem remains that the decrease in size implied an increase of the resonant frequency, whereas the typical vibrations (roadways, human body, machinery ...) have fundamental frequencies around 100 Hz⁷. Those generators will then need to operate on input frequencies far below their resonant frequencies. Nonresonant generators and generators in which the input frequency is decoupled from the power-generating resonant frequency seem to be a solution.

But a new type of device offers the possibility of using high-frequency resonant structures with low-frequency input vibrations. The fabrication and operation of arrays of piezoelectric “nanogenerators” have been proposed using a bundle of ZnO nanowires⁸. A similar effect was shown with GaN nanowires⁹. The choice of ZnO was made because of its remarkable semi-conducting and piezoelectric properties. All those

works are made by the prolific Prof Z. Wang team from Georgia Tech. After the elaboration of ZnO based nanostructure¹⁰, they have demonstrated that it was possible to convert mechanical energy into electrical one thanks to these bundles of ZnO nanowires¹¹ with power density around 80 nW/cm², which is quite enough to supply nanodevices¹². Other ZnO nanowires based innovative nanodevices have been proposed: piezoelectric FET (without grid electrode)¹³, piezoelectric diode¹⁴ or piezoelectric humidity sensor¹⁵. The last application proposed was the conversion of biomechanical energy into electricity by a muscle-movement-driven nanogenerator¹⁶. However this attractive concept has been recently refuted by another team from the Max Planck Institute of Microstructure Physics on 2 major points and the effects exposed by the Georgia Tech team has been demonstrated with the use of Si nanowires, not known for its piezoelectric ability, showing then that the energy harvesting does not come from the nanowires.

Some research on magnetoelectric materials can be useful to energy harvesting devices. It has been proposed to nanostructure the magnetoelectric material or to add carbon nanotubes to improve the magnetostriction of those materials. A combination of a piezoelectric layer embedded between two magnetoelectric layers can be used as an energy harvesting device¹⁷.

5.7.3.2 Large scale

Research in the field of nanoscience and nanotechnology related to those means of electrical energy production is very limited. This can be explained by the fact that the processes involved implied essentially mechanical mechanisms such as turbines powered by wind, water, steam ...

It can be noted however that some research on materials are useful. The integration of carbon nanotubes¹⁸ to strengthen and reduce the weight of the materials, used to realise the blade can help to enlarge their size, confront them to harder conditions, and made therefore wind turbine more energy-efficient.

5.7.4 Additional demand for research

5.7.4.1 Small scale

5.7.4.2 Large scale

5.7.5 Current situation within EU

5.7.5.1 Small scale

5.7.5.2 Large scale

5.7.6 Applications and perspectives

5.7.6.1 Small scale

- Self powered autonomous nano-scale devices from sensor to actuator
- intelligent distributed sensing for health, safety-critical systems or environment monitoring
- Walk (shoes), body motion (textile) energy harvesting

5.7.6.2 Large scale

- Diversification of the grid electric sources

5.7.7 References & Literature

¹ Direct Energy Conversion, S. Angrist, Allyn & Bacon, 1982.

² Review of Energy Harvesting Techniques and Applications for Microelectronics; L. Mateu and F. Moll: Proceedings of the SPIE Microtechnologies for the New Millenium **5837**, 359 (2005)

³ Vibration to electric energy conversion; S. Meninger, J. Mur-Miranda, R. Amirtharajah, A.P. Chandrasakan, and J. H. Lang: IEEE International Symposium on Low Power Electronics and Design 48 (1999)

⁴ http://www1.eere.energy.gov/windandhydro/wind_basics.html

⁵ "World Wind Energy Report" (2008)

⁶ http://www1.eere.energy.gov/geothermal/geothermal_basics.html

⁷ Energy Scavenging for Wireless Sensor Networks: With Special Focus on Vibrations"; S. Roundy, P.K. Wright, and J.M. Rabaey: Kluwer Academic, Boston, (2004)

⁸ "Small-scale energy harvesting through thermoelectric, vibration, and radiofrequency power conversion"; N.S. Hudaka and G.G. Amatucci: Journal of Applied Physics **103**, 101301 (2008)

⁹ Generation of electricity in GaN nanorods induced by piezoelectric effect; W. S. Su, Y.F. Chena, C.L. Hsiao and L.W. Tu: Applied Physics Letters **90**, 063110 (2007)

¹⁰ "Nanobelts of Semiconducting Oxides" ; Z.W. Pan, Z.R. Dai, Z.L. Wang : Science **291**, 1947 (2001).

¹¹ "Piezoelectric Nanogenerators Based on Zinc Oxide Nanowire Arrays" ; Z.L. Wang, J.H. Song : Science **312**, 242 (2006)

¹² "Toward high output-power nanogenerator" ; J. Liu, P. Fei, J. Zhou, R. Tummala, Z.L. Wang : Applied Physics Letters **92**, 173105 (2008)

¹³] "Piezoelectric Field Effect Transistor and Nanoforce Sensor Based on a Single ZnO Nanowire" ; X. Wang,X. Wang, J. Zhou, J. Song, J. Liu, N. Xu, Z.L. Wang : Nano Letters **6**, 2768 (2006)

¹⁴ "Piezoelectric Gated Diode of a Single ZnO Nanowire" ; J.H. He, C.L. Hsin, J. Liu, L.J. Chen, Z.L. Wang : Advanced Materials **19**, 781 (2007)

¹⁵ "Polymer functionalized piezoelectric-FET as humidity/chemical nanosensors" ; C.S. Lao, Q. Kuang, Z.L. Wang, M.C. Park, Y. Deng : Applied Physics Letters **90**, 262107 (2007)

¹⁶ "Converting Biomechanical Energy into Electricity by a Muscle-Movement-Driven Nanogenerator"; R. Yang, Y. Qin, C. Li, G. Zhu, and Z.L. Wang, Nano Letters **9** 1201 (2009)

¹⁷ “Recent advancements in magnetoelectric particulate and laminate composites”; S. Priya, R. Islam, S. Dong and D. Viehland: *Journal of Electroceramic* **19**, 147 (2007)

¹⁸ “Science for a better world: Bayer annual report” (2007)