Human Body, the Power Source

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Abstract— Energy harvesting in unconventional way has been a topic of discussions and research for over more than two decades. Conventional sources of energy are becoming costlier and environment hazardous. So by the force of need, researchers are being compelled to find unconventional sources of energy. The human body is a huge source of power and energy. This power can be tapped and used as a source of energy. Enormous growth in research for harvesting this human body power is in progress. The use and need of portable and wireless electronic devices is increasing. If human body energy could be used for powering these devices then it would bring in technological revolution in design and development of these electronic devices. In this paper, we would wish to highlight this potential source of renewable and green energy.

Keywords: harvesting power; portable electronic devices; human body power; renewable energy

I. Introduction

There is a growing need for renewable sources of energy. The generally known renewable sources of energy are natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat. To add to these known sources of energy, human body is also a good potential source of energy and power. Generating energy from human body dates back to history when automatic mechanical wrist watches were invented. Wherein, manual rewinding of the wrist watch spring was not done on regular intervals, instead a half round plate pivoted at centre on installed in the watch. By the movements of the wrist the half round plate would oscillate, rewinding the watch spring automatically. The Human Body, unbeatable creation of nature, is a huge source of power and energy. We can say that the human body is a walking-talking power pack. A human body has 206 bones and 360 bone joints. Every bone joint is a potential source of power generation. Mechanical or motor movements of these joints are controlled by bioelectrical signals, which are generated by the brain. A human performs various motor movements in his day-to-day activities. Walking, running, jogging, sitting and speaking are the major movements carried out and generating power from these movements is a challenge for the researchers. The joint movements of ankle, knee, hip, chest, wrist, elbow, upper arm, side of the head, and back of the head can be targeted to extract energy. Sensors or power extracting devices can be placed at these joints. Harvesting energy from the human body motion is becoming a focus point for research. The mechanism of power extraction form human body joint is analogous to charging of battery through dynamo fitted on the engine of a vehicle. The energy harvested will be an ecological green and clean energy. Attempts have been made to harvest human body energy by placing generators on shoes, bag packs and ankle bracelets.

The inputs to conventional power generation have fixed or known frequency and amplitude. For example the amount and rate at which water falls on a hydro generator is controlled at a fixed rate, steam injected on propellers of power generating turbine is controlled. But the input, human movement used for power generation is not fixed and prediction of its frequency of movement is very difficult. Hence design of sensors for power extraction from human body movements is the greatest challenge.

The energy harvesting can be broadly categorized in two methods: Macro and Micro harvesting [1].

II. Harvesting of Power

A. *Macro Energy Harvesting*

In macro level energy harvesting, renewable resources like wind, solar and tide are used. The energy or power that is harvested from these sources is noticeably huge but comparable less than that from conventional thermal or hydro. The financial investment in setup of these macro level harvesting systems is huge and very much dependent on the nature.

For wind harvesting systems, windmills are erected on hill tops and rotation of the blades of windmill is dependent on the velocity of wind. As these windmills and located on remote hill tops, their maintenance and repairs are of great concern.

Solar harvesting systems are totally dependent on sun shine. On gloomy days, rainy days and winter season the energy harvested is negligible. Solar water heating systems are very common in residential and commercial communities.

Tidal harvesting systems are only feasible along the sea shores and hence their energy is limited to sea shore areas. Even though tides are predictable but the amount of energy harvested is very less.

To summarize, these macro level systems are large scale, energy harvested is very less, unreliable and totally dependent on the nature. To manage these harvesting systems expertise is required in energy management and distribution system. The basic aim of these harvesting systems is to reduce oil or petroleum dependency.

B. *Micro Energy Harvesting*

Micro level harvesting is also a renewable resource of energy but the amount of energy that can be harvested in ultra-low. The systems used in micro level harvesting are also ultra-small. As the energy harvested is ultra-small, they are used to power portable and wireless electronic devices like wrist watches, mobiles, etc. These micro systems are used to power the batteries of electronic devices. Electromechanical, electromagnetic and electrostatic are types of micro harvesting systems.

Electromechanical harvesting systems are basically piezoelectric based. Wherein, mechanical deformation of piezoelectric crystal directly generates electric energy. The major advantages of piezoelectric systems are it has highest energy density, no separate voltage source required and direct voltage output.

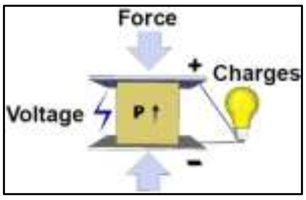

Fig. 1: Example of an electromechanical energy harvesting

Electromagnetic harvesting systems are basically vibration based; mass-spring system. Vibration motion is fed to a suspended permanent magnet damped by a known spring constant. The vibrating magnet induces current in coil due to electromagnetic coupling. The advantages of electromagnetic systems are high output current and robustness.

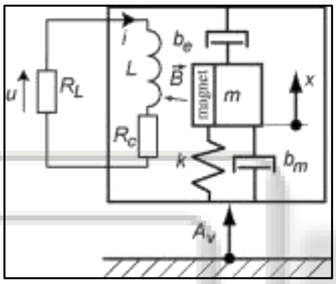

Fig. 2: Example of an electromagnetic energy harvesting

Electrostatic harvesting systems are basically piezoelectric based. Variable capacitance effect is used to generate charges from a relative motion between two plates. The advantages of electrostatic systems are high output voltage and easy coupling to electronic circuits.

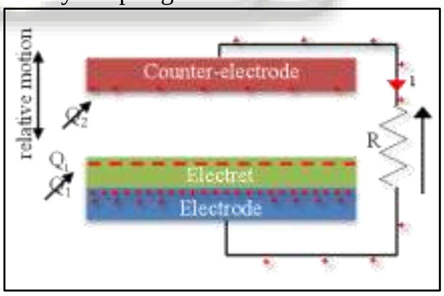

Fig. 3: Example of an electrostatic energy harvesting

To summarize, energy from micro harvesting system are used to drive ultra-low power consuming electronic devices.

III. PIEZOELECTRIC ENERGY HARVESTING

Comparing the three types of energy harvesting methods, mention in previous section, it is observed that the advantages of piezoelectric type is most desirable and hence the most preferred method. Piezoelectric transducer, which is an electromechanical converter, undergoes mechanical vibrations and produces electricity. The piezoelectric effect is exerted in two ways – one direct effect and second converse effect. The phenomenon of generation of a voltage under mechanical stress is known to as the direct piezoelectric effect. The phenomenon of the ability to convert an applied electrical potential into mechanical strain energy is converse effect. The direct phenomenon is used for energy harvesting.

Materials possessing piezoelectric properties are available in nature and also artificial or manmade. Piezoelectric materials available in nature are in the form of crystals, they are Berlinite (AlPO4), Cane sugar, Quartz, Rochelle salt, Topaz, Tourmaline Group Minerals, and dry bone (apatite crystals). The manmade types are Barium titanate (BaTiO3), Lead titanate (PbTiO3), Lead zirconate titanate (Pb[ZrxTi1-x]O3 0<x<1) - More commonly known as PZT, Potassium niobate (KNbO3), Lithium niobate (LiNbO3), Lithium tantalate (LiTaO3), Sodium tungstate (NaxWO3), Ba2NaNb5O5, Pb2KNb5O15, polymer – Polyvinyledene fluoride (PVDF).

The piezoelectric materials that exist naturally as quartz are not interesting properties for the production of electricity, hence artificial quartz were developed. The artificial piezoelectric materials such as PZT (Lead Zirconate Titanate) was developed having advantageous characteristics. Piezoelectric materials belong to a larger class of materials called ferroelectrics. One of the properties of a ferroelectric material is that the molecular structure is oriented such that the material exhibits a local charge separation, known as an electric dipole. Electric dipoles are orientated randomly throughout the artificial piezoelectric material composition.

When a very strong electric field is applied, the electric dipoles reorient themselves relative to the electric field; this process is termed poling. Once the electric field is removed, the dipoles maintain their orientation and the material is then said to be poled. After the poling process is completed, the material will exhibit the piezoelectric effect. The mechanical and electrical behavior of a piezoelectric material is governed by combination of the following two equations:

The materials electrical behavior: $D = \varepsilon E$ (1)

Hook's law: $S = sT$ (2)

where D is electric displacement, ε is permittivity, E is electric field strength, S is strain, s is compliance, T is stress

The coupled strain-voltage equation:

$$S = s^{E}T + d^{t}E \quad (3)$$

is converse piezoelectric effect

$$D = \varepsilon^{T}E + dT \quad (4)$$

is direct piezoelectric effect

These equations, known as the "coupled" equations, reduce to the well-known stress-strain relationship at zero electric field, and the electric field and charge displacement relationship at zero stress.

Piezoelectric effect is presented by 6 directions of the axes, three Cartesian directions plus the shear around the three axes[2].

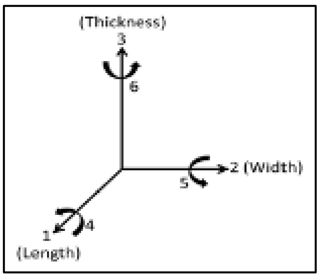

Fig. 4: Piezoelectric axes

Electrical parameters are in the X, Y and Z directions whereas mechanical parameter includes also the shear about the three axes. Piezoelectric materials have a built-in polarization, and therefore respond differently to stresses depending on the direction. The direction of polarization for piezoelectric materials is usually direction 3. There are two primary modes of electromechanical coupling for piezoelectric materials. Piezoelectric materials are generally employed in mode 33 or in mode 31. In mode 33 the mechanical stress is applied in direction 3 and the electrical field takes place also in the direction3. In mode 31 the mechanical stress is applied in direction 1 whereas the electrical field is obtained in direction 3.

IV. PIEZOELECTIRC ENERGY HARVESTING FROM HUMAN BODY

Potential human power sources are body heat, breathing, blood pressure, arm motion, typing, and walking or actively through user actions such as winding or pedaling and power from these sources may be recovered passively [3].

The idea of harvesting energy from human motion is based on the amount of energy used by the body. A considerable amount of human energy is released from the body in the forms of heat and motion; which opens a way for the development of technologies that can harvest this energy for powering electronic devices.

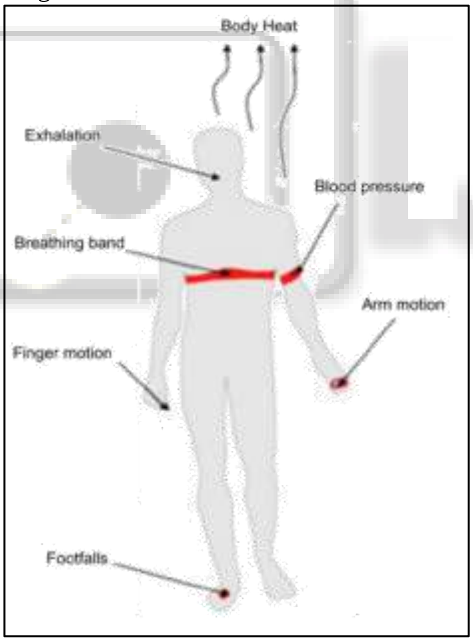

Fig. 5: Energy sources from human body

The major body motions are during walking that we can consider as potential energy sources like heel strikes, center of mass motion, shoulder and elbow joint motion during arm swings, and leg motions, such as ankle, knee, and hip motions. To estimate the potential power of each motion, an integrative analysis of the body motion has to be done [4].

Every motion the body makes provides an opportunity for acquiring energy. Harvesting energy from human body motion means converting kinetic energy of motion to electrical energy. Human-induced motions are challenging for energy harvesting design because of their low-frequency, aperiodic, and time-varying characteristics. The mechanical energy can be generated from of bending forces, tension and compression.

A major restriction of conventional energy harvesting systems are that they are typically designed for only one rectilinear degree of freedom, while normal human movements occur in three dimensions and involve a high degree of rotational, rather than oscillatory motions[5].

Considering the above restriction, piezoelectric method for energy harvesting is most preferred and researched upon. Piezo crystal can deform in all the three dimensions and respond to compression, tension and bending forces.

A piezoelectric energy harvester consists of one or two piezoceramic layers is glued to a cantilevered beam. The harvester beam is mounted on a vibrating host structure. The dynamic strain induced by vibration in the piezoceramic layer(s) generates an alternating voltage output across the electrodes fused to the piezoceramic layer(s).

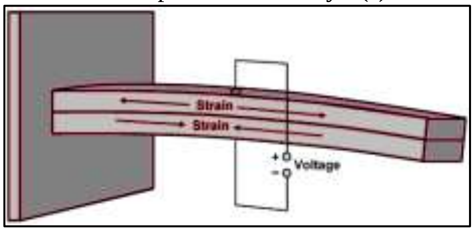

Fig. 6: Cantilevered beam with piezoceramic layers.

An alternating voltage output is obtained due to the oscillatory base motion applied to the structure. It is required to convert the alternating voltage output to a constant voltage using a rectifier bridge (AC-to-DC converter) and a smoothing capacitor in order to reach a constant level of voltage for charging a small battery or a capacitor using the harvested energy. Since the voltage levels for charging batteries and capacitors are not arbitrary, it is usually required to use a DC-to-DC converter (step-up or step-down) in order to regulate the rectified voltage output of the piezoceramic according to the voltage requirement of the specific charging application [6].

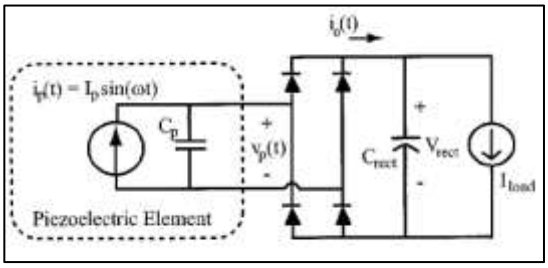

Fig. 7: Piezoelectric element model with ac–dc rectifier and load

The energy harvested from a single layer piezoelectric crystal is very low and may not be sufficient to charge a battery or trigger an electronic circuit. Hence multilayer piezoelectric crystals are used or single crystals are connected in series to multiply the generated voltage output.

Types of human body energy harvesting techniques:

A. *Force driven*

The bending of piezoelectric materials attached to human body parts is employed. Direct mechanical force exerted by human body parts act on the transducers and the electrical output generated is proportional to the force exerted. It is the most common method employed for energy harvesting.

Fig. 8: Force driven technique

B. Acceleration driven

The acceleration-driven systems have the common problem of a large device size which greatly reduces their acceptability for integration with human body. Motion energy harvesters are inertial devices driven by their acceleration.

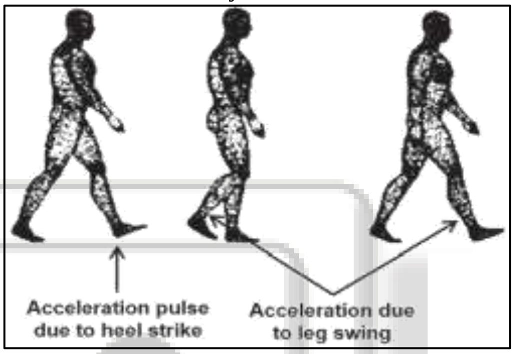

Fig. 9: Acceleration driven technique

Maximum power theory says the maximum power is obtained at resonance. Wherein, the maximum output power is obtained within a small frequency range under oscillatory accelerations [7]. While human-induced motions have low-frequency, aperiodic, and time-varying characteristics, hence resonant systems do not apply for energy harvesting. Researchers have used non-resonant harvester architecture, which can respond over a broad range of vibration frequencies and amplitudes, and the use of a multi-directional architecture that can respond to motions in multiple axes. They are frequency up-conversion techniques or non-resonant techniques.

V. Conclusion

Power generated from human body is wasted in the form of heat and motion, the energy from motion can be extracted. From the three methods of micro energy harvesting, piezoelectric method is most preferred and used. Piezoelectric energy harvesting is very useful in implantable or wearable electronic devices.

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