Fully Self-Powered Electromagnetic Energy Harvesting System

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Abstract: *This paper describes the use of piezoelectric polymers in order to harvest energy from people walking, together with the electronics needed to increase energy transfer and storage efficiency. An electrostatic generator was also included in order to increase energy harvesting. There have been independent solutions in increasing the harvesting efficiency either on the mechanical harvester or on its power management circuitry. Here, piezo electric transducers are used in the keys of mobile phones and also in keyboards of personal computers. Piezo electric transducers are used to convert the mechanical energy applied in the keys to electrical energy i.e. an equivalent electric voltage. The obtained voltage will be read by the Atmel microcontroller so that it will be utilized properly for an electric load e.g. Bulb. This paper can be used in smart mobile phones and also in personal computers to use the charge or voltage for its operation by itself. Coupling an energy harvesting system to existing battery in these devices may significantly improve their energy sustainability that at present is one of its biggest limitations.*

Keywords: Piezoelectric Energy Harvester, mechanical energy, piezoelectric transducers, sustainability

1. Introduction

Piezoelectric Energy Harvester uses the piezoelectric effect to convert normally wasted mechanical energy in the form of vibrations into useable electrical energy [1]. Any application where sensing is needed and there is a consistent vibration to harvest from can benefit from the Voltage. Being a developing country the power consumption is increasing on large scale to meet the growing need of the people. Power generation is widely based on the non-renewable sources and these sources being depleting some means have to be found for power saving. In the last few years, there has been an increasing demand for low-power and portable-energy sources due to the development and mass consumption of portable electronic devices like mobile phones, personal computers etc.

The increased utilization of the portable, implantable, and wireless systems in daily applications has triggered the need for compact and efficient energy harvesting devices to power these systems, as frequent battery replacement would be impractical. Furthermore, the reduced power demand in new generation integrated circuits has allowed the use of energy harvesters as primary power sources in small systems. As a result, temporary energy reservoirs like batteries can be replaced with energy storage elements in such systems, which are continuously being charged by using the ambient energy sources such as heat, light, and vibration [2].

Among these energy sources, vibration is particularly attractive due to its abundance. Some vibration sources in the environment are vehicle motion, human movements, and seismic vibrations that vary in frequency and amplitude, and these vibrations can be harvested by using different methods such as electrostatic, piezoelectric, and electromagnetic transduction [3] [4]. However most of these vibrations occur at low frequencies (<10Hz), leading to low power levels at the output, introducing some challenges in the efficient design of these systems.

Most of the past studies have used a simple matched resistive load at the output of the harvester module, and reported the generated AC power delivered to this load. Such studies tend to overestimate the available power to a realistic DC load since they exclude the rectification losses. An improvement is to use simple bridge rectifiers and smoothing capacitors for processing the harvested AC signal, but the AC/DC conversion efficiency tends to be low since a considerable portion of the generated power needs to be consumed for turning on the rectifying diodes. Only a small number of publications discuss more sophisticated power processing implementations of AC/DC conversion with power transfer optimization. Most of such work has been done for piezoelectric transducers, as their output voltage is relatively high.

There is an imminent need for a compact energy harvesting System-on-Package (SOP) that comprises of an energy harvester module and integrated interface electronics which can efficiently rectify low AC voltage levels from low frequency vibrations. The state-of-the-art EM energy harvesting systems are usually large and have low power density due to poor power conversion efficiency [5] [6].

1.1 Different Harvesting Methods:

a. Thermal Energy Harvesting

The body temperature changes when it receives or provides energy. In this situation, the molecules are in constant motion, and this agitation is measured by temperature [7].

Only by temperature difference can energy extraction from thermal reservoir (e.g. body) be guaranteed. The possibility of conversion between heat and work has been restricted to thermal machines. The Second Principle of Thermodynamics, developed by Sadi Carnot in 1824, is stated as follows: "To be continuous conversion of heat into work, a system must perform cycles between hot and cold sources continuously. In each cycle, is extracted a

certain amount of heat from the hot source (useful energy), which is partially converted into work, being the remainder rejected to the cold source (energy dissipated)".

b. Electromagnetic Energy Harvesting

An electric field always produces a magnetic field and, conversely, a time variable magnetic field always produces an electric field. The induction law of Faraday describes the modification that a magnetic field will induce in an electric current. In turn, the equation of Ampere-Maxwell states the modification generated by an electric field into a magnetic field [8].

There are already several types of electrical generators that use mechanical vibrations, including those who are present in watch and radio frequency circuits. These are able to use the energy recovered from the natural environment. There are two types of mechanical generators: those who use the relative motion of objects in which the generation system is connected and those that use rigid body motion. Both systems use the electromagnetic induction principle convert movement into electric power. The relative motion of the armature corresponding to the permanent magnet is given by the object relative motion in which the generating system is fixed.

c. Piezoelectric Energy Harvesting

Since piezoelectricity is generated by applying stress to a piezoelectric element, Young's constant measures the ratio between stress and strain of the element.

$$Y = \frac{F/A}{\Delta L/L}$$

F = force (N)
A = area of element (m^2)
L = length of element (m)
ΔL = change in length of element (m)
 As the element vibrates, there will be an elastic potential, u_e, present.

$$u_e = Y \cdot \frac{\Delta L^2}{2L_0} \cdot A_0$$

L_o = length of element (before compression)
A_o = area of element (m^2)
The energy generated from a piezoelectric element (by applying stress) is modeled by:
E = (piezoelectric coefficient) u_e
The unit conversion analysis of how a piezoelectric element can generate power (in Watts) is shown below.

E = (piezoelectric coefficient) u_e

$$= \frac{N}{m^2} \cdot \frac{(\Delta m)^2}{m^2} \cdot m^2 = N \cdot m$$

Energy has units of Joules = Nm
        Power from piezoelectric element =>

$$\frac{Energy}{time} = \frac{N \cdot m}{s} = \frac{J}{s} = Watts .$$

Here I develop a vibrational energy harvesting system utilizing high efficiency interface electronics for AC/DC conversion is presented. The system attains high power generation density when subjected to low frequency vibrations. A custom high efficiency active rectifier has been designed at the core of the harvester system to

convert a wide range of induced AC signals to DC with minimum power consumption [9] [10].

d. Proposed Energy Harvesting System

Previous attempt to harvest energy from various sources, and some also use super capacitors instead of batteries to address the battery aging problem. However, they either waste much available energy due to impedance mismatch, or they require active digital control that incurs overhead, or they work with only one specific type of source [11]. The disadvantages of existing system were

1) Additional work is needed in areas such as harvesting methods
2) The harvesting efficiency can easily drop by one to two orders of magnitude if MPPT is not performed

In the last few years, there has been an increasing demand for low-power and portable-energy sources due to the development and mass consumption of portable electronic devices.

This paper describes the use of piezoelectric polymers in order to harvest energy from people walking and the fabrication of a shoe capable of generating and accumulating the energy. In this scope, piezoelectric used as energy harvesting element was introduced into a bicolor sole prepared by injection, together with the electronics needed to increase energy transfer and storage efficiency. An electrostatic generator was also included in order to increase energy harvesting [2] [3].

The advantages of proposed system were

1. Reduce maintenance costs.
2. Energy harvesting allows for devices to function unattended and eliminates service visits to replace batteries.
3. Provide long-term solutions.
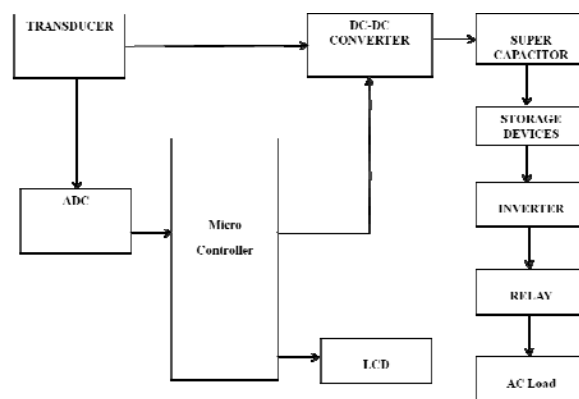
2. System Architecture and Working Principle

Figure 1: Functional Block Diagram

The kinetic energy resulting from the ambient vibrations is Converted to electrical energy through a low cost and simple piezoelectric energy harvester (transducer).The produced electrical energy is in the form of analog voltage, in order to convert this analog voltage to digital

voltage we use analog to digital converter (ADC) with minimum power consumption and displayed in the liquid crystal display (LCD).

The produced digital voltage is of the order of MV. In order to rectify the produced low dc voltage here we use DC to DC booster which converts a source of direct current (DC) from one voltage level to another. The output of DC to DC booster is the order of 1.5 v. Here by using DC to DC booster we can Eliminates need for dual supplies the output of DC to DC booster is continuously stored in the super capacitor. Super capacitor is having capacitance values greater than any other capacitor type available today. The most significant advantage super capacitors have over batteries is their ability to be charged and discharged continuously without degrading like batteries do. This is why batteries and super capacitors are used in conjunction with each other in our design as a storage device.

The voltage stored in the battery is fed to the inverter which converts the dc voltage to ac voltage. The produced ac voltage is used as a source to lamp through relay. Here relay act as a switch.

While calculating efficiency A portion of the generated power is consumed by the operation of the rectification and ADC conversion block hence while calculating the efficiency of the total system, the consumption of the active rectifier should also be considered. The system efficiency is defined as: system efficiency = $(P_{out} - P_{ar})/P_{input} * 100$

A transducer can be defined as a device capable of converting energy from one form into another. Transducers can be found both at the input as well as at the output stage of a measuring system. The input transducer is called the sensor, because it senses the desired physical quantity and converts it into another energy form. The output transducer is called the actuator, because it converts the energy into a form to which another independent system can react, whether it is a biological system.

We can distinguish six different energy domains: (1) radiant, (2) mechanical, (3) thermal, (4) electrical, (5) magnetic and (6) vibrational system. Here we use vibrational energy system as a source. Here we use piezoelectric transducer as an energy harvested module which harvests the energy from ambient vibrations which are occurred at low frequency. The harvested energy is stored in the storing device. Here we use battery as a storage device. Here we use some electronic circuitry to modulate the harvested energy. The electronic circuitry includes dc to dc booster, super capacitor, inverter and relay.

3. Results and Discussion

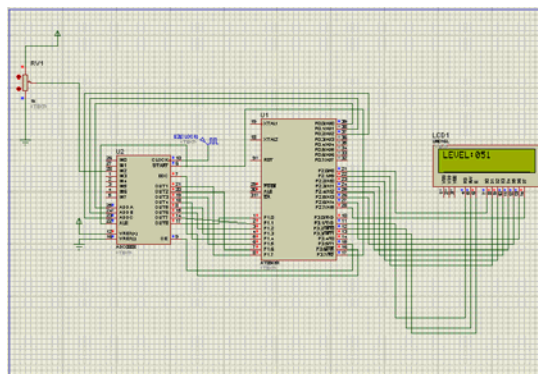Based on the concept discussed the circuit was designed and simulated in proteus

Figure 2: Simulation of node in proteus

Based on the simulation above the node was constructed as shown in below figure

Figure 3: Working Model

The above fig shows the working model of our energy harvesting system which contains piezo electric transuder and electronic circuitry to harvest the energy from ambient vibrations.

Figure 4: Voltage when no pressure applied

The above figure indicates that when pressure is applied the volume of harvested energy is zero.

Figure 5: voltage when pressure applied

The above figure indicates the increase in volume of harvested energy when some pressure is applied.

4. Conclusion

This study presents the design and realization of a compact and highly efficient electromagnetic vibration harvesting system including an electromechanical energy harvester and interface electronics which is implemented as a system-on-package. A low cost, simple, and in-house EM energy harvester module has been used as the power generator with high power density which harvests energy from ambient low frequency vibrations (< 10 Hz). High efficiency active interface electronics has been designed and implemented to convert the generated AC voltage to dual rail DC. EM energy harvester uses a dedicated coil to power up the active converter, making the system fully autonomous. The system has been implemented and validated under different electromechanical excitation conditions.

5. Acknowledgment

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