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Design of Piezoelectric-Thermoelectric Hybrid Energy Harvester for Wireless Sensor Network

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Abstract—**With rising demand for long-term and autonomous sensor nodes, energy harvesting, an innovative powering strategy has received remarkable attention over several years. The major sources of energy that can be harvested are solar energy, thermal energy and vibration energy. However, as of today, only a single source of energy is being looked at for harvesting. As an extension to this efficient-multiple-energy harvesting is also possible. This thesis aims to develop a multi-source energy harvesting system with power conditioning circuit for wireless sensor node in Industrial applications. The maximum energy is harvested using two transduction methods, Piezoelectric and Thermoelectric. MPPT algorithm is employed to enhance output power and for better impedance matching. Performance results are presented for each one of harvesting methods using MATLAB/ Simulink software.**

Index Terms— **Energy Harvesting, Hybrid, Piezoelectric, Thermoelectric,**

I. Introduction

In the past decades, energy harvesting has been studied as a power source for low power electronics circuits and wireless sensor nodes. Energy Scavenging has been proved as efficient wireless power supply. Energy scavenging is the process of extracting energy from ambient environment through a variety of sources of energy. The available energy for harvesting is primarily provided by ambient light (artificial and natural lighting), radio frequency, thermal sources and mechanical sources.

Piezoelectric transduction method is employed for converting vibration into electricity for powering the wireless electronics, whereas thermo-electricity is a direct translation of temperature gradient to electric voltage through seebeck effect. As per research, only a single source of energy harvesting is insufficient to power the low power devices. Thus, to surmount low power issues related to single source harvesting, multi-source system utilizing multiple ambient energy sources for harvest is employed which increases the overall efficiency.

Wireless sensor node is power-driven by vibration energy harvesting system which converts the wasted vibration to constructive electrical energy. Wireless sensor networks[2] not only consumes low power in the range of milli- or micro- Watts and uses piezoelectric material, that converts the ambient mechanical vibrations into electrical energy and this model gives Energy efficiency of about 73.8 %.

A Thermoelectric energy harvester is designed to power the wireless sensor networks (WSNs) for building energy management (BEM) applications has been build and tested[3]. A charge pump/switching regulator two-stage ultra-low voltage step-up DC/DC converter design has been presented to boost the <0.5V output voltage of TEG to functional voltage level for WSN (3.3V). The design concept, device simulation, circuit schematic, and the measurement results are also presented. The test results of the prototype device show 25% end-to-end conversion efficiency in a wide range of input temperatures voltages.

To get over the low power issues related to single source harvesting, need to opt for multi-source system utilizing multiple ambient energy sources for harvest. A cantilever type multi-source energy harvester [4] that produces electrical energy from two ambient energy sources (vibration and thermal) for WSN was developed that gave total power output of 1.91nW. These outputs from the transducer block are not adequate to drive the loads connected. Thus, a switch based DC-DC boost converter [5] has been designed to boost output voltage. DC/DC converters [6] that include impedance matching consideration into its designed MPPT algorithm to address the multi-source impedance mismatch issue.

II. Energy harvesting system

The design of the proposed multi-source energy harvesting system is depicted in “Fig. 1”.

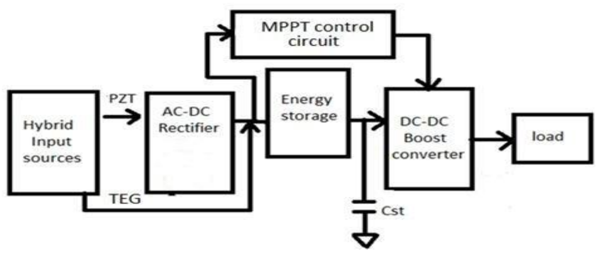

Figure 1. Proposed model for energy harvesting.

The proposed EH system captures temperature gradient and vibration from the ambient environment via TEG and PZT respectively from plants like boilers, generators etc. MPPT algorithm along with DC-DC Boost converter is used for better impedance matching. Extracted energy is stored in super capacitor which is used to power the load.

The MPPT control circuit is used to adjust the duty cycle of DC/DC converter depending on inputs

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from energy harvester block to ensure that the output voltage is stable and maximum power is harvested.

A. Piezoelectric energy harvester

Two layer bender mounted as a cantilever beam and a mass positioned on the free end, as shown in "figure 2", has been used for two prime reasons. Firstly, the cantilever configuration results in the highest average strain for a given force input, and the output power is directly related to the average strain produced in the bender. Secondly, this mounting result in the lowest resonance frequency, lower resonance frequency is important since the targeted input vibrations are low frequency (60–200 Hz)

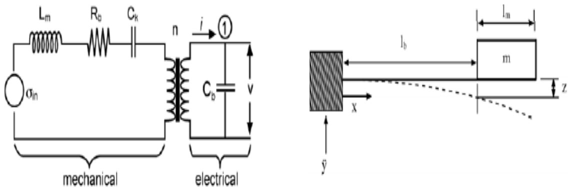

Figure 2. (a) Circuit representation of the piezoelectric generator. (b) A schematic diagram of the generator.

To predict and optimize the piezoelectric generation, the PZT beams had been modelled individually as spring mass damper systems, coupled to the piezoelectric structure[7], as in Figure2(b). The piezoelectric is connected to the load resistance in parallel for energy harvesting. Mechanical structure elements had been coupled to the electrical system as shown in Figure 2(a). From this, the system equations had been developed and are defined in Equations (1) and (2)

$$\sigma in = Lm\dot{S} + RbS + \frac{S}{Ck} + nVpi \qquad (1)$$

$$ipi = Cb\dot{V}pi + \frac{Vpi}{Rpi} \qquad (2)$$

Here Lm is equivalent inductor indicating the mass or inertia of the generator, Rb is equivalent resistance representing mechanical damping, σin is equivalent stress generator that is caused due to the stress caused by the input vibrations, Ck represents the equivalent capacitor for the mechanical stiffness, and $\dot{S}$ is strain rate. The coupling of piezoelectric is represented by transformer with an equivalent turn ratio n.

B. Thermoelectric energy harvester

Thermoelectric energy harvesting is the process of converting thermal energy into an electrical by using thermoelectric generator (TEG) made of thermocouples. Thermoelectricity describes the relationship between heat flow and electrical potential in conducting materials. The ability to generate electrical power from a temperature gradient in materials is due to the Seebecks effect.

If two junctions are maintain at the different temperatures i.e. Tcj and Thj , an open-circuit voltage (Voc) proportional to the temperature difference, ΔTteg, would be developed. For thermoelectric power generator (TEG), which is composed of n thermocouples connected electrically in series and thermally in parallel, the open circuit voltage, Voc, of the TEG is given as [3]:

$$Voc = s * \Delta Tteg = n * \alpha(Thj - T \qquad (3)$$

where α and s represents the Seebecks coefficient of a thermocouple and a TEG respectively.

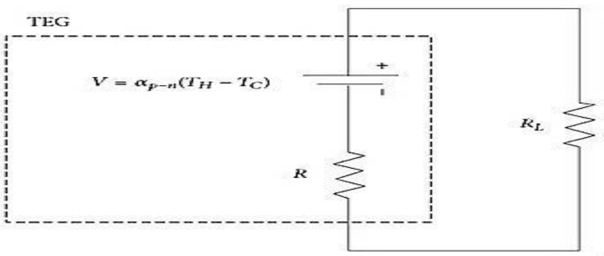

Figure 3. (a) Circuit representation of the piezoelectric generator. (b) A schematic diagram of the generator.

The output power PL, delivered by the TEG to the load, RL, can be expressed as:

$$P_l = I^2_{teg} R_l \qquad (4)$$

III. Numerical Results

Simulations for both the transducers is done using MATLAB/Simulink platform. The output characteristics of the TEG, PE and PV transducers are measured.

The transducer parameter values of the equivalent PZT circuit element are given in "Table 1".

Table 1: The value of PZT circuit element

Equivalent Parameters	Values
Input voltage Vin	380 mV
R_b	114Ω
L_m	2.3 mH
C_k	2.27 mH

The voltage and current waveform for PEH is shown in "figure 5".

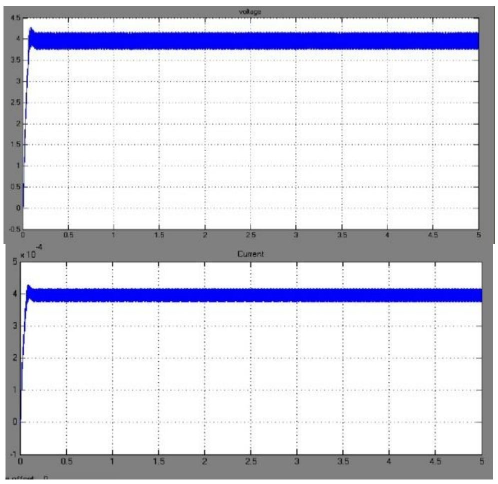

Figure 4. Voltage and current characteristics of PEH

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The current output was found to be 0.4 mA and voltage was found to be 4 volts with applied vibrations of around 70 Hz. The obtained power PEH is around 1.6 mW.

The transducer parameter values of the equivalent thermoelectric circuit element are given in "Table 2".

Table 2: The value of Thermoelectric circuit element

Equivalent Parameters	Values
Input voltage Vin	380 mV
R	114Ω

The voltage and current waveform for PEH is shown in "figure 6".

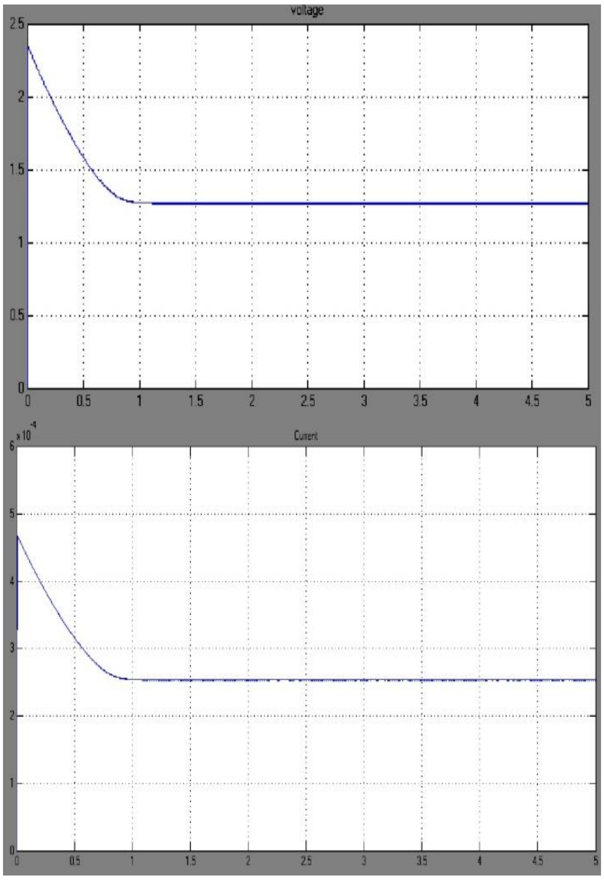

Figure 5. Voltage and current characteristics of TEG

The voltage output was found to be 1.25 Volts and current was found to be 0.25 mA. The obtained power for TEG is around 313 μW with temperature difference of 30°C.

Both piezoelectric energy harvester and thermoelectric energy harvester were combined to obtain a multi-Source energy harvester. The output voltage and current waveform for multi-source energy harvester is shown in "figure 6"

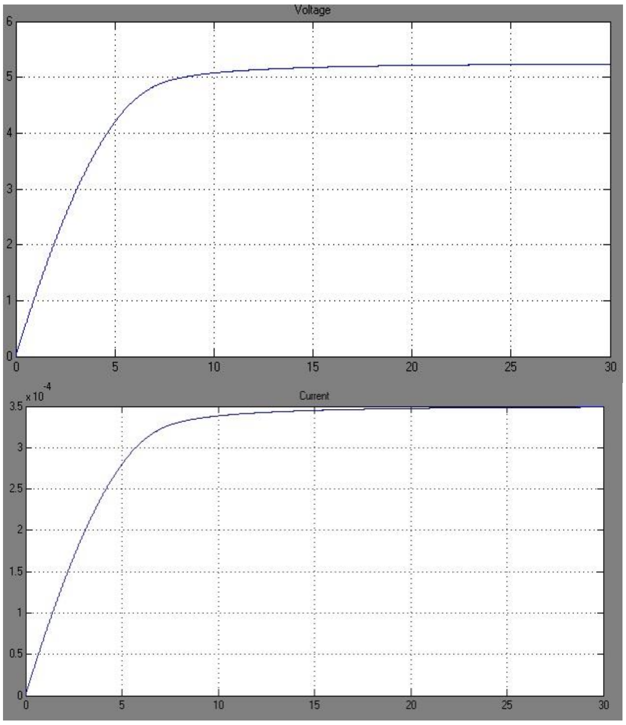

Figure 6. Voltage and current characteristics of multisource energy harvester.

The current output was found to be 0.35 mA and voltage was found to be 5.25 volts for multisource energy harvester. The obtained power for multisource is around 1.84 mW.

Conclusions

A multisource energy harvester was designed with piezoelectric and thermoelectric transduction techniques. Modified perturb and observe algorithm was developed to obtain maximum power point along with DC-DC boost converter for impedance matching. Piezoelectric energy harvester gave power output of 1.6 mW, thermoelectric energy harvester gave power output of 313 μW. The output of the multisource energy harvester was found to be around 1.84 mW. Hence the output power of multisource energy harvester is more compared to the single source energy harvester.

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