DESIGN OF PIEZOELECTRIC-PHOTOVOLTAIC 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 being harvest. 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 Photovoltaic. 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.

Keywords— AEnergy harvesting, Transduction, Photovoltaic, Piezoelectric.

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 scavengingis 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; Photovoltaic transduction converts photon energy into electricity. 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 %.

Photovoltaic energy transduction is the method of converting photons from the sources like solar and/or artificial light into electrical energy. Photovoltaic energy is extracted by using photovoltaic (PV) cells.

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”.

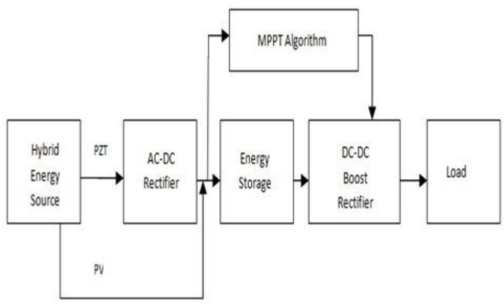

Fig.1. Proposed Energy harvesting circuit.

The proposed EH system captures light energy and vibration from the ambient environment via Photovoltaic 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 supercapacitor 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 from energy harvester block to ensure that the output voltage is stable and maximum power is harvested.

2.1. Piezoelectric energy harvester

Two layer bender mounted as a cantilever beam and a mass positioned on the free end, as shown in "fig. 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)

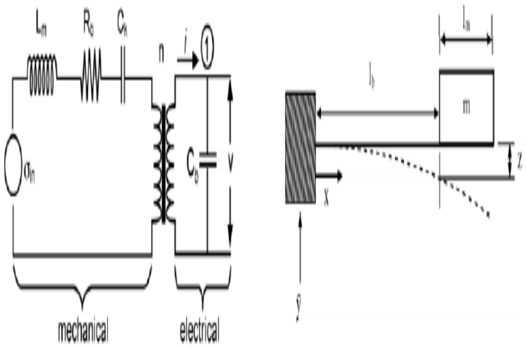

Fig.2. (a) Circuit representation of the piezoelectric generator. (b) A schematic diagram of the generator.

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 Ṡ is strain rate. The coupling of piezoelectric is represented by transformer with an equivalent turn ratio n.

2.2 Photovoltaic energy harvester

PV cell generates a voltage of around 0.5 to 0.8 volts which primarily depends on the semiconductor material and the built-up technology. This voltage is inadequate for powering a device. Hence, to obtain advantage from this technology, tens of PV cells are coupled in series to form a PV module.

The electrical equivalent of a PV cell is shown in "Fig. 3". It consists of a current source (Iph), a diode, a series resistance (Rs) and a shunt resistance (Rsh) [8].

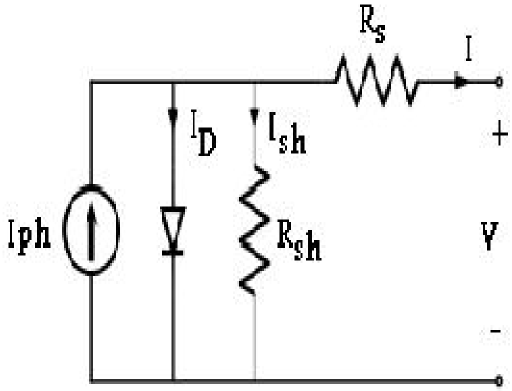

Fig.3. Equivalent circuit of PV cell

In view of the electrical equivalent, the current to the load can be given as:[9,10]

$$I = Iph - Ist\left(exp\frac{q(V + Rs\,I)}{NKT} - 1\right) - \frac{V + Rs\,I}{Rsh} \qquad (3)$$

In this equation, *Iph*is the photocurrent, *Ist*is the reverse saturation current of the diode, *q* is the electron charge, *V* is voltage across the diode, *K* stands for Boltzmann's constant, *T* is the junction temperature, *N* is the ideality factor of the diode, and *Rsh*and *Rs*are the shunt and series resistances of the cell, respectively.

The PV cell photocurrent depends on the radiation and the temperature according to equation (4)

$$Iph = [Isc + Ki(T - 298)]\frac{\beta}{1000} \qquad (4)$$

where*Ki*=0.0017 A/◦C is the cell's short circuit current temperature coefficient and β is the solar radiation (W/m2) of the PV cell.

III. RESULTS AND DISCUSSION

Simulations for both the transducers is done using MATLAB/Simulink platform. The output characteristics of the 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
N	1:17
C_b	3.58 μF

The current and voltage waveform for PEH is shown in "figure 4".

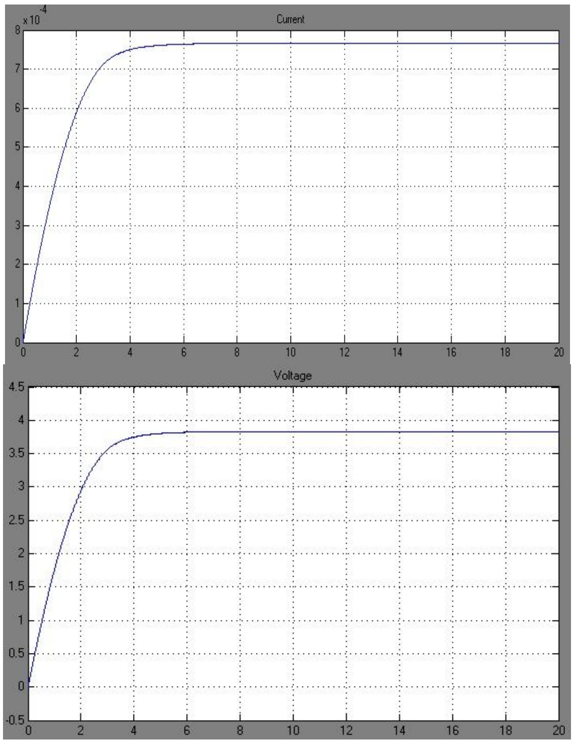

Fig.4. Current and voltage characteristics of PEH

The current output was found to be 0.78 mA and voltage was found to be 3.8 volts with applied vibrations of around 70 Hz. The obtained power PEH is around 2.96 mW.

The photovoltaic Energy Harvester was designed for Irradiation of 1000 W/m^2 with 36 cellls connected in series. The series resistance was found to be 0.023 Ω, shunt resistor around 58Ω, Isc of around 0.028A.
The voltage and current waveform for Photovoltaic energy harvester is shown in “fig.5”.

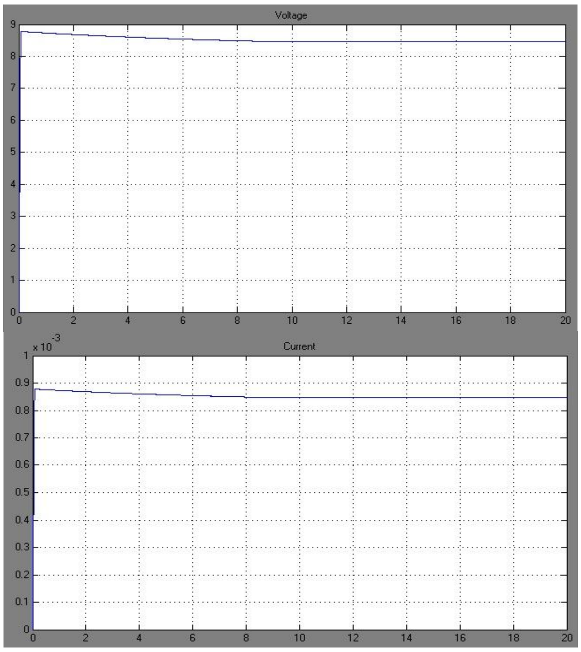

Fig.5. Current and voltage characteristics of Photovoltaic energy harvester

The voltage output of the photovoltaic energy was found to be 8.5 Volts and current was found to be 2.85 mA. The obtained power is around 6.8mW.
Both piezoelectric energy harvester and photovoltaic 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”

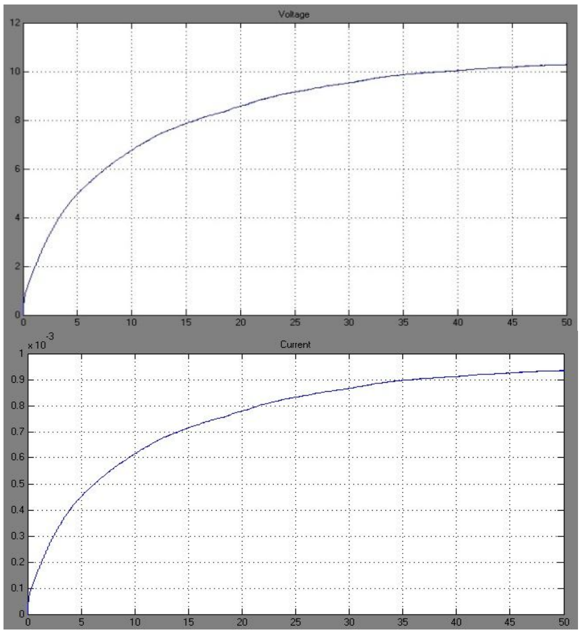

Fig.6. Current and voltage characteristics of multisource energy harvester

The current output was found to be 0.93 mA and voltage was found to be 10.2 volts for multisource energy harvester. The obtained power for multisource is around 9.6mW.

CONCLUSIONS

A multisource energy harvester was designed with piezoelectric and photovoltaic transduction techniques. Modified perturb and observe algorithm was developed to obtain maximum power point along with DC-DC boost converter for impedance matching.

1. Piezoelectric energy harvester gave power output of 2.96mW,
2. Photovoltaic energy harvester gave power output of 6.8 mW.
3. The output of the multisource energy harvester was found to be around 9.6mW.
4. Hence the output power of multisource energy harvester is more compared to the single source energy harvester.

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