COMPARATIVE STUDY, DESIGN AND SIMULATION OF ENERGY STORAGE DEVICE FOR PIEZOELECTRIC ENERGY HARVESTER

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ABSTRACT

Piezoelectric materials have been used to transform ambient mechanical vibrations into electrical energy according to the principle of it. The electrical energy thus produced by this principle is too low to directly recharge the rechargeable batteries, so the need is to improve voltage. Therefore in our work we have used the improved voltage as a stored energy to power portable devices. For the above statement we have designed our circuit with the help of modeling, simulation and experimental results for two types of non-adaptive harvesting circuits using TINAPRO software. In our work capacitors have been charged using improved Ottman's et al non-adaptive harvesting circuit to determine the charge time and maximum capacity of a capacitor to which that can be charged, with the help of rectifier and a static converter transform the electrical energy into a suitable form to charge the portable devices. Values of stored electrical power are reported and commented.

Keywords: PZT, PDPE, EHEV, HC

I. Introduction

Over the last two decade, several articles have reported the use of transduction mechanisms for low power generation from ambient vibrations. As stated by Williams and Yates [2], there are three basic mechanisms to electric energy conversion that are electromagnetic [3], electrostatic [4] and piezoelectric [5] transductions. The conversion of mechanical vibration-to-electricity was first investigated and proposed by Williams and Yates in 1996 [2].

Piezoelectric materials have been used to transform ambient mechanical vibrations into electrical energy according to the principle of it [1].

The main advantage associated with piezoelectric materials is the flexibility towards energy harvesting. These materials are able to convert mechanical ambient energy into electrical energy because of piezoelectric effect. However, the major limitation faced in the piezoelectric energy harvesting is that the average harvested power is too less. Therefore, usually, some storage means are used to store and accumulate the harvested energy. We are taking references of one of the first researchers to realize the need for power storage circuitry was Starner et al in 1996 that uses the idea of using a capacitor and rechargeable battery for power harvesting [6]. This concept was taken a step further by Umeda et al in1997, who investigated the use of a capacitor with piezoelectric materials [7]. They theoretically and experimentally tested the circuit in various configurations to determine the optimal design. Shortly after the publication of this work, a power harvesting patent was issued to Kimura et al. in 1998 for a means of storing the energy from a piezoelectric device in a capacitor [8]. Much of the early researches into power harvesting considered the use of capacitors as a way to store energy and have dealt with extracting maximum power from the piezoelectric materials or developing circuitry to store the energy [9]. In our present work firstly we have taken simulated results of two non-adaptive harvesting circuits by designing the appropriate circuit with the help of TINAPRO software. Secondly design a new rectifier element using a schottky barrier diode and taken simulated result of it, by comparing the simulate results of first circuit and second circuit it is concluded that the result of second circuit shows the improved output.

II. Principle of Piezoelectric Effect

The piezoelectric effect was first demonstrated by the Currie brothers in 1880 [1]. If the piezoelectric material is subjected to a voltage drop (i.e. an electrical potential difference applied across its electrodes), it deforms mechanically. This is called the converse piezoelectric effect (CPE) and it was deduced mathematically (after the discovery of the direct piezoelectric effect) from the fundamental principles of thermodynamics by Gabriel Lippmann in 1881 and then confirmed experimentally by the Curie brothers.

Following are the two principles of piezoelectric effect:

(a) First form is direct piezoelectric effect (DPE) that describes the material's ability to transform mechanical strain into electrical charge (the material acts as a sensor).

(b) Second form is converse piezoelectric effect (CPE), which is the ability to convert an applied electrical potential into mechanical strain energy (here the material acts as an actuator).

The phenomenon of direct piezoelectric effect (DPE) is shown in Fig.1 [12].

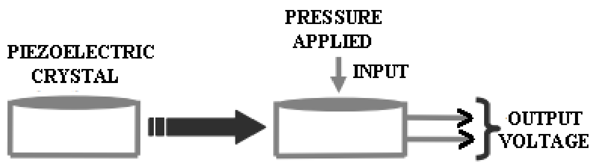


Figure 1: Principle of direct piezoelectric effect (PDPE)

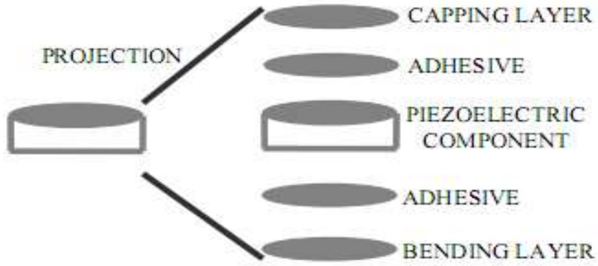


Figure 2: Structure of piezoelectric element

III. Experimental Setup

A. Pulsating DC output of PZT

The electrical energy at the output of the piezoelectric material is a strong and irregular function of time; hence, a full wave bridge rectifier is needed to produce a DC output signal which is shown in Fig. 3. Generally for the rectifier circuit silicon diode is preferred, but the main limitation of these rectifiers is the low power extraction. Therefore we have design bridge rectifier circuit using schottky barrier diode.

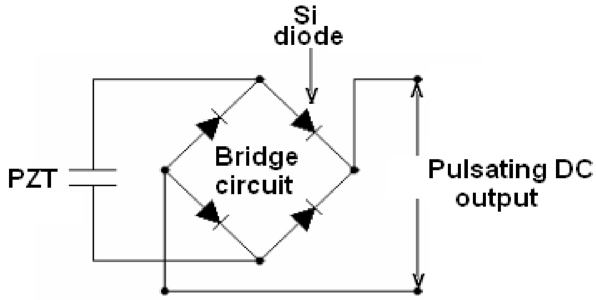


Figure 3: Basic rectifier circuit

The process of experiment was divided into three parts which were energy harvested from vibration environment, harvesting circuit used and improvement made in the Ottoman's Energy harvesting circuit.

***B. Energy Harvesting from Vibration Environment* (**EHEV)

The piezoelectric material selected for a power harvesting application can have a major influence on its functionality and performance. Most common type of piezoelectric material used in power harvesting applications is lead zirconate titanate, piezoelectric ceramic, or piezo ceramic also known as PZT. The piezoelectric device used in this experiment consists of a brass plate with a piezoelectric patch (PZT) bonded on its surface. The dimension of piezoelectric device used is shown in Fig. 4. The thickness of brass plate and piezoelectric patch were 0.4 mm and 0.2mm respectively. The PZT used is flexible as it allows high deflection and it could sensation high pressure.

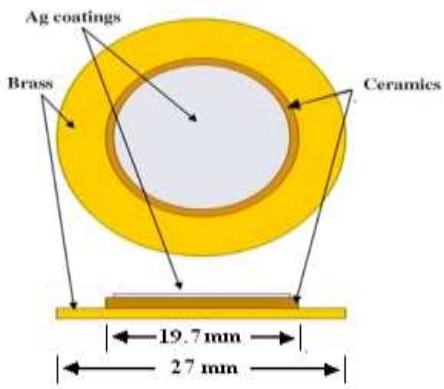


Figure 4: Dimensions of piezoelectric element

When the piezoelectric material is subjected to the pressure produces equivalent electrical signal as a direct piezoelectric effect (DPE). As the frequency of mechanical vibration with pressure applied increases, the output power from piezoelectric material also increases. Based on piezoelectric fundamentals, the behavior of piezoelectric device is investigated for the resonant frequency. The value of resonant frequency is taken as 50 Hz and maximum generated voltage is 10 volts. The experimental setup for this experiment is shown in Fig. 5.

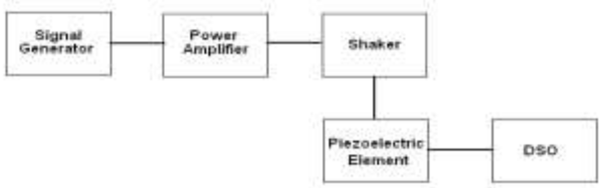
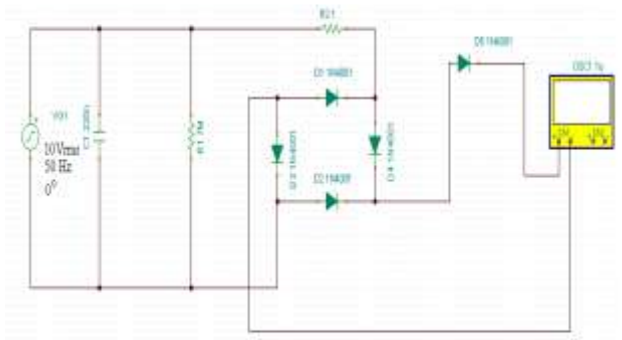


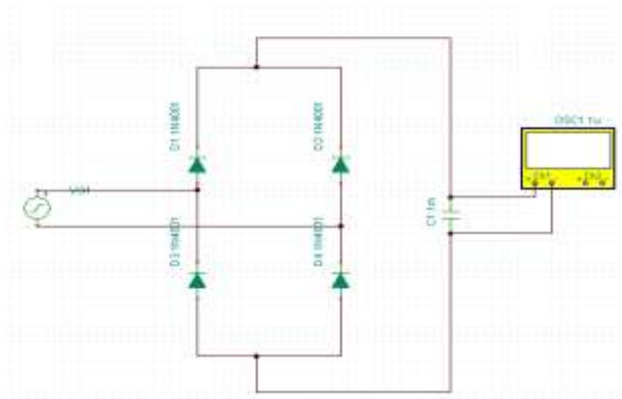
Figure 5: Block diagram of Experimental setup

C. **Harvesting Circuit used (**HC)

There are two types of non-adaptive harvesting circuits considered by Guan *et al.,* [11] and Ottman *et al.,* [10]. Fig. 6.1(a, b) show the type of circuits considered.



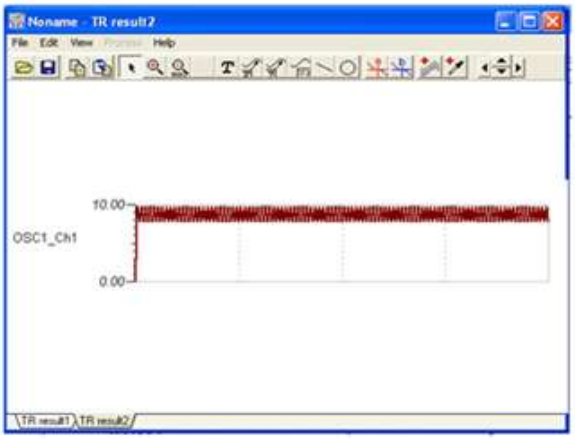
(a)



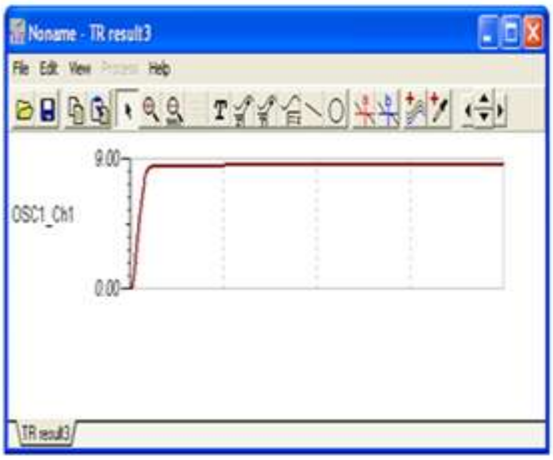
(b)

Figure 6.1: Harvesting circuits (a) proposed by Guan *et al* [11] and (b) by Ottman *et al* [10]

Both the circuits shown in Fig.6.1 (a ,b) is analyzed using TINAPRO software which uses sinusoidal input frequency of 50 Hz & maximum voltage of 10 V given as source. The output from both the circuit is shown in Fig. 6.2.



(a)



(b)

Figure 6.2: Output voltage obtained using circuit used by Guan’s circuit (a) and used by Ottman’s circuit (b)

From the Fig. 6.2 (a), we see that output voltage using Guan’s circuit have more ripples where as the output voltage from Ottoman's circuit was in steady state nearing to peak value 9 V . This is due to the use of capacitor in the circuit Fig. 6.1 (b).In the present study the Ottoman’s non-adaptive harvesting circuit has been used throughout this study.

D. Improvement made in ottoman’s energy harvesting circuit

As the maximum output voltage from piezoelectric material is 10 V we have replaced Silicon diodes used by Ottoman’s by Schottky barrier diode because this diode has voltage drop about 0.33 V where in Silicon diode, this value would drop approximately 0.66 V. Energy storage devices used are capacitors of capacities of 0.1F, 0.22F, 1.0F and 1.5F with voltage rating of 10.5V. The experimental setup is shown in Fig. 7.

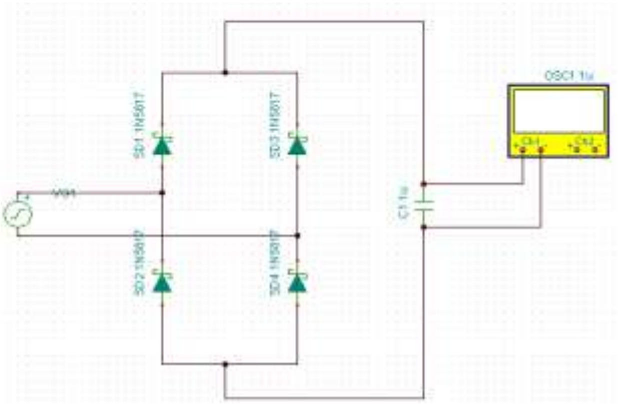


Figure 7: Full wave rectifier using Schottky barrier diodes

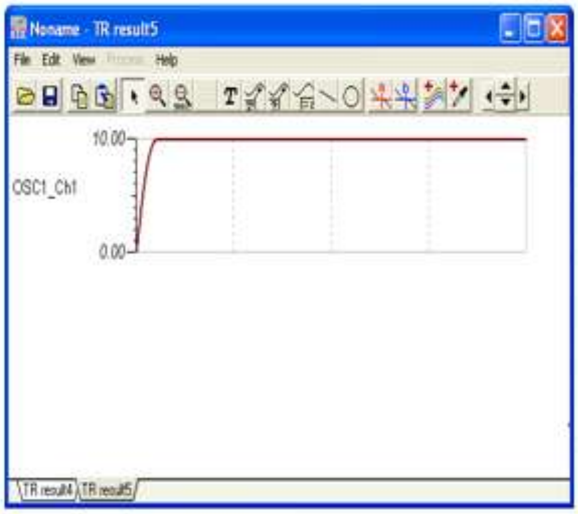


Figure 8: Output voltage by using Schottky barrier diodes

From the simulation results from TINA PRO software it is summarized that the Schottky barrier diode is the best element for rectification as shown in Fig.8.

IV. Tests Conducted on various Storage devices

There are four storage devices tested in order to see the performance of storing energy generated from piezoelectric element and rectifier circuit. Experiments are performed using 50Hz frequency signal. The results are shown in Fig. 9.1 and 9.2.

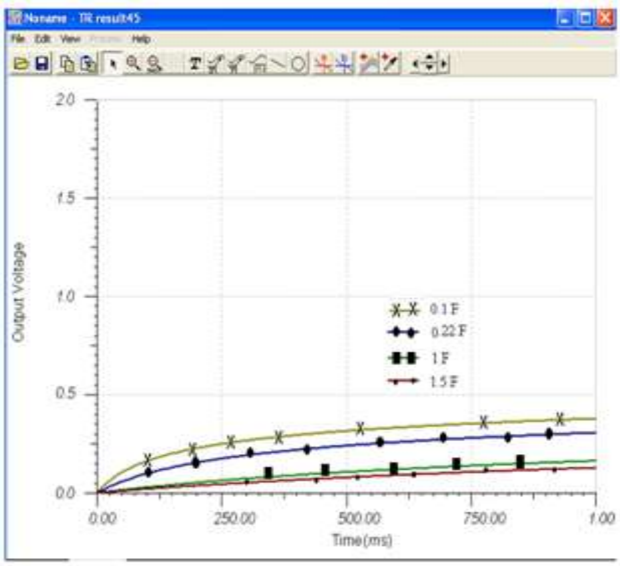


Figure 9.1: Output voltage using Silicon diodes

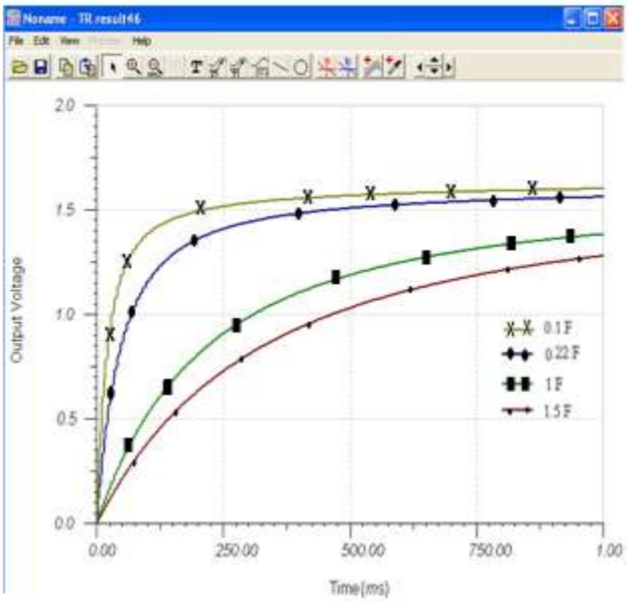


Figure 9.2: Output voltage using Schottky barrier diodes

V. Result

From the above simulations it is observed that the capacitor having the value of 0.1F can be charged to maximum output voltage of 1.5 volts using Schottky barrier diode with in 125 ms and same capacitor having the value of 0.1F can be charged to maximum output voltage of 250 mV by using Silicon diode with in 750 ms

VI. Future Scope

The proposed work portrays the concept of piezoelectric energy harvesting and from the results it is obvious that if the dimension of piezoelectric material is large than more electrical energy can be obtained which can be used to charge the capacitor to greater extent for the further application. Therefore based on dimension and operating frequency of piezoelectric material various applications requirement will be meet.

VII. Conclusion

The main objective of this research is to study and analyze the potential of piezoelectric sensor and element of rectifier circuit as a mean of harvesting energy. To achieve the objective, experimental study had been done where piezoelectric device been used to charge capacitor from vibration environment. It has been proved that electrical power can be generated through piezoelectric material from pressure applied. The study proved that the converted energy can be stored as proven through charging a battery.

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