

## HYBRIDISED ENERGY HARVESTER USING PIEZOELECTRIC AND RADIO FREQUENCY FOR LOW POWER DEVICES

**Olakanmi Oladayo O.<sup>1</sup>, Soenu Shakiru<sup>2</sup>, Ajibola Oladokun<sup>3</sup> and Benyeogor Mbadiwe<sup>4</sup>**

<sup>1, 2,3,4</sup> Electrical and Electronic Engineering, University of Ibadan, Ibadan, Nigeria

**Abstract:** *The reduction in the amount of power required by electronic devices has rapidly increased the number of their users. Meanwhile, most of the end users in the developing countries could not fully enjoy these devices due to instability in electricity supply, thereby denying them the comfortability brought by such devices. Several breakthroughs recorded in energy harvesting has spurred interest on how to increase the efficiency of the available energy harvesters. In this paper, a novel energy harvesting technique, using piezoelectric transducer and RF-DC receiver converter is developed, and also an approach to improve the efficiency of the energy harvester is proposed.*

**Keywords:** *Energy harvester, energy, generation, Piezoelectric, Radio Frequency*

### 1. INTRODUCTION

Electricity is a scarce commodity in Africa – annual consumption is 518 KWh in Sub-Saharan Africa, the same amount of electricity used by some individual firms in the U.S. within a month. Across the continent only 10% of individuals have access to the electrical grid, and of those, 75% come from the richest two quintiles in overall income. Less than 2% of the rural populations of Nigeria, Malawi, Ethiopia, Niger, and Chad have access to electrical power. Electrical provisioning in Africa has generally only reached wealthy, urban middle class, and commercial sectors, bypassing the region's large rural populations and urban poor. It is common knowledge today that Africa's moment of economic lift-off revolves around the mobile revolution happening in the region. But true economic transformation, the kind that will lift all boats, will only happen once the continent solves its power problems.

The lack of reliable power is causing huge difficulties for entrepreneurs in the region, raising their costs of doing business, and dampening investor confidence. Despite strong economic growth – the World Bank estimates Sub-Saharan Africa's growth this year to stand at 4.0% – access to electricity remains a struggle. The question is what is happening to different energy sources? Why are they not used to solve energy problem in African countries as it is in the developed nations like USA, UK, Germany, and Russia etc. There are five viable sources of electrical energy that most nations adopt to provide electricity for their citizens and economic activities. These are thermal, hydro, nuclear, wind and solar. Most non-renewable energy sources such as fossil fuels: coal, petroleum, and natural gas definitely do not support sustainable development peculiar to developing nations. The focus is now on renewable energy sources. However, most of these renewable sources are not being utilized to their optimum capabilities due to the constraints imposed by these sources. Some of these constraints are highlighted below:

#### Solar Energy Source

- Only effective when sun is set with optimum radiation.
- Required large area of open land.
- Excessive high maintenance cost.

#### Geo Thermal

- Emit poisonous gas.
- Excessive high initial cost.
- Heavily depend on water.

#### Hydro

- Releases large amount of carbon-di-oxide and methane.
- Area near dams is degraded.
- Disturbs ecological balance near dam.

## **Biomass**

- Inefficient energy output.
- Methane gas evolved.
- Degrades environment.

The search for cheap alternative energy source has become an important subject in most research publications. An alternative source that provides a green alternative power source to power low power devices will significantly boost the economy and other areas of life. Although, renewable energy source seamlessly fit into this categories, however, it is riddle with some performance bottlenecks. These are limiting its prospect as a cheap solution to energy problem. Then, if renewable sources fail, then what is the hope of Africa for a sustainable medium level energy for driving their economy? The answer to this lies on ambient sources such as Radio wave and Micro-Electro- Mechanical System (MEMS)-Based energy generators. The flexibility associated with piezoelectric materials makes them very attractive for power harvesting. Piezoelectric materials possess a large amount of mechanical energy that can be converted into electrical energy, and they can withstand large strain magnitude. In the past, mechanical vibration and free RF have been taken as either a disturbance, hazardous or non- existing. As it stands, the energy from the road vibrations produced during millions of daily car trips in places like Lagos, Accra, Pretoria, Ibadan, and Port-Harcourt is simply being wasted. Also, vibrations from places like churches, event centers, bus stops and lecture theaters which can be easily converted to electricity are being wasted. However, putting enough piezoelectric energy harvesters under the surface of the asphalt, arguably produces zero-carbon energy source. In the same vein, energy in form of radio wave abound in the sky at no cost. Every household can tap this free energy with a well design antenna and converter for low power devices. However, there are few performance bottlenecks associated with MEM and RF wave energy generator such as low output.

The major focus of this paper is an approach on how these two sources can be implemented at medium level so their output can be increased and combined for effective use to power low power devices such as phone, laptop, street light, traffic light etc.

## **2. RELATED WORK**

Several works had been done on piezoelectric energy harvesting. Kumar et al in [3], designed a prototype energy harvester and power conditioning circuit. Their design involved the optimization of the power extracted from piezoelectric diaphragms cascaded under floor tiles. They developed an efficient technique to capture the generated piezoelectric energy via dedicated integrated circuits and boost the generated energy using a converter, to obtain a regulated output for charging Smartphone batteries. In [4], Kim et al conducted extensive research on harvesting energy from mechanical vibrations. They analyzed the performance of various types of vibration devices, piezoelectric materials and developed mathematical models of the vibration energy from reviewed piezoelectric harvesters.

Similarly, Ottman et al., in [2], developed an approach for harvesting electrical energy from mechanically excited piezoelectric elements which offer capacitive source impedance when driven by mechanical vibrations of varying amplitudes. They developed an analytical expression for the optimal power flow from a rectified piezoelectric device and a unique energy harvesting circuit that is capable of achieving the optimal power flow. Their developed harvesting circuit consisted of an ac–dc rectifier with an output capacitor, an electrochemical battery, and a switch-mode dc–dc converter that controls the energy flow into a load battery used for energy storage. An adaptive control technique for the dc–dc converter was used to continuously implement the optimal power transfer theory and maximize the power stored by the battery. The Experimental results of their research work reveal that use of the adaptive dc–dc converter in piezoelectric energy harvesting increases power transfer by over 400% as compared to when the card converter is not used.

A novel high efficiency piezoelectric energy harvesting system was proposed by Do et al, in [1], to increase extracted power from piezoelectric elements. By using two synchronized switches, the efficiency of the rectifier in the system proposed by Do et al is doubled. To increase the conversion efficiency of the rectifier the passive diode of the conventional rectifier is replaced by an active diode. Simulation results of their proposed system showed that the power extraction efficiency of the rectifier is 3.5 times that of the conventional full bridge rectifier, thus more than 93% of power conversion efficiency was achieved. A Low-drop regulator (LDO) was used to regulate voltage at the output of rectifier with a maximum efficiency of 90% and ripple voltage of 3mV. This resulted in an overall efficiency of 83.3% for their proposed piezoelectric harvesting system.

Many methods have also been proposed in order to improve the harvested power of micro electromechanical systems (MEMS) micro- generators. One of these methods is the selection of a proper coupling mode of operation. One of these modes is called 31 mode, which considers the excited vibration force being applied perpendicular to the poling direction (pendent beam). The other mode is called the 33 mode in which the force is applied on the same side as the poling direction. Between the two modes, the 31 mode is the most commonly used, which produces a lower coupling coefficient  $k$  than the 33 mode. The second method to improve harvested power requires changing the device configuration, accomplished by adding multiple piezoelectric materials to the harvester. Also, introduction of cantilever beam configuration demonstrated that, a highest power could be generated using this configuration under lower excitation frequencies and load resistance energy harvesting.

Meanwhile, bridge and single diode are popular rectification technique for RF energy harvesting systems that work with low input power. Most existing research work used single rectifier topology, however all those reported works needs high- level input voltage or the energy harvester be in proximity to the RF sources. For a rectifier circuit to work with lower input power and the same time higher output voltage level is required, a voltage doubler and multistage converter circuit can be used. However, due to high number of diodes, the power losses is more compared to single diode circuit. Furthermore, converter circuit has been designed in CMOS arrangement due to the circuit size, circuit losses were acceptable. However, this type of converter circuit introduces complex in rectifier circuit design and was not robust enough and normally used in delicate application such as in wireless structural health monitoring sensors.

### 3. MATERIALS AND METHODOLOGY

The major bane of MEM and RF sources is their low outputs, most of the past efforts to improve their outputs, especially with MEM, has been at micro application level. This has not yielded much improvement as expected for powering common home devices. In this section we increase the output of MEM and RF sources to medium level by working around shape, and arrangement of piezoelectric, improve the receiver antenna of RF, and aggregating the output of RF and MEM. Also, we considered the use of bridgeless converter with efficient impedance matching circuitry on the receiver antenna of the RF. This circuitry operates with low input power and generating high output voltage. The bridgeless rectification circuit has a similar topology as a boost converter. The only difference is that the switch of the conventional booster is replaced with capacitor C1 for high-frequency operation for the proposed circuit. L1, L2, L3 and C1 are the parameters of the matching LCL network.

For the piezo arrangement, a matrix like architecture as shown in Figure 3, is used. In this arrangement  $n$  number of piezo cells are connected in  $m$  series, all the  $m$  series are then connected in parallel to form  $m \times n$  matrix and a strata of these matrices form medium piezoelectric generator. The main goal is to reduce the total internal resistance of the cells thereby increasing the current flowing capacity of the arrangement. The parallel arrangement increases the generator's output current. Meanwhile, the voltage from a series connection is high but with low current whereas the current in parallel is good while voltage is poor. The matrix arrangement enjoys the voltage increase through the series connection while parallel connection increases the output current.

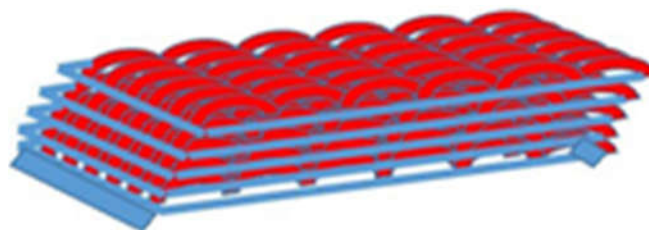


Figure 1: Matrix arrangement for piezoelectric transducers

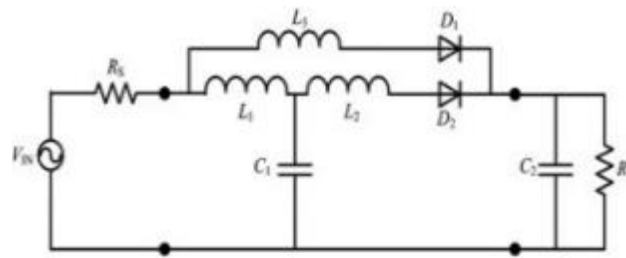


Figure 2: Bridgeless converter

### 3.1. PIEZOELECTRIC ENERGY HARVESTER

Figure 3 depicts the schematic of all the stages in the construction and fabrication of the harvester. A foot mat with dimension 22cm by 14cm was obtained and then divided into a matrix of 510 using meter rule and pen. The piezoelectric crystals are then laid on the marked position. The top and bottom of the foot mat are joined using a spring with high elasticity in order to provide succulence whenever a mechanical force is applied. The chosen foot mat is selected such that the top mat is capable of efficient diffusion of the applied force to the piezo-electrics.

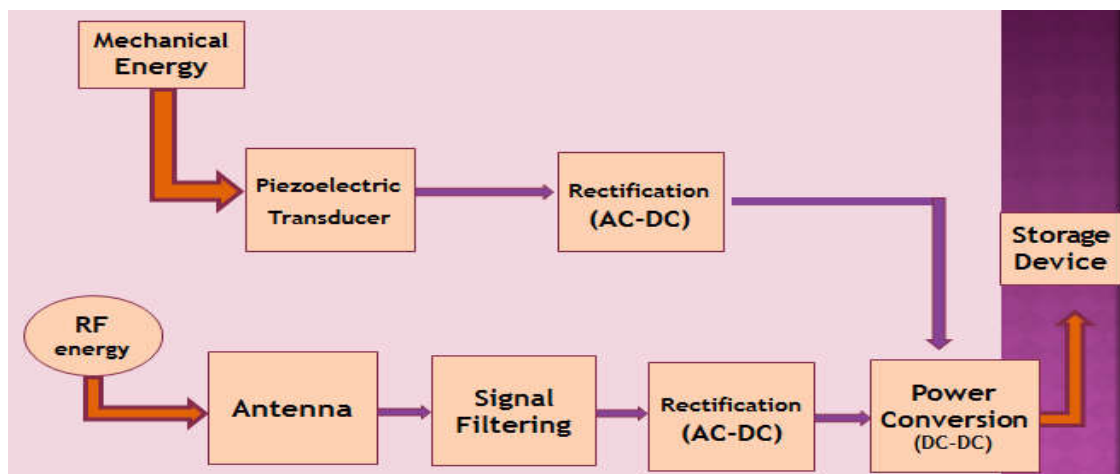


Figure 3: The block diagram of hybridized energy harvester.

Though the output voltage and current generated by a single piezoelectric crystal are very small, usually in millivolts and milliampere respectively. This is improved when many of this piezo are connected in cascaded form. The practical implication of this is that the connection is done in such a way that the piezos are connected in series (column-wise) and in parallel (row-wise) such that the voltages are added up in series while current are added up in parallel. Consequently, the laid piezoelectric crystals were then joined by connecting wires. Mathematically,

$$\text{Output voltage, } V = V_{1,1} + V_{1,2} + \dots + V_{1,n}$$

$$\text{Output current, } I = I_{1,2} + I_{2,1} + \dots + I_{m,1}$$

We assumed that all piezos generate equal voltage and current when mechanical pressure is evenly applied to the generator.



Figure 4: The cascaded piezoelectric transducer

### 3.1.1 Rectifier Circuit

The rectifier circuit employed is a full-wave bridge rectifier. The output of a piezoelectric crystal (voltage and current) is alternating current. Each piezos' row is rectified separately with different rectifier. The dc output of the all the bridge rectifiers are connected in parallel so that the currents are added up while maintaining the voltage value of each rectifier.

### 3.1.2 The energy storage

Since the dc output of the piezo energy harvester tends to have varied values due to the variation in the applied mechanical pressure, it is then necessary to store this dc output in a storage device (like battery or supercapacitor) through which a low-power consuming loads can be powered. For this work, a supercapacitor (1000 $\mu$ F, 35V dc), as shown in Figure 5, was used. The supercapacitor was first charged to its peak voltage by the energy harvester before it was used to power loads.



Figure 5: supercapacitor used as the storage

## 3.2 RF ENERGY HARVESTER

The other part of Figure 3 shows all the stages in the RF energy harvester. All the phases involved in the construction and fabrication of the RF energy harvester part of the generator are:

- a) Selection of antenna.
- b) Design for RF receiver prototype.
- c) Assembling of components.

### 3.2.1 Selection of antenna

There are several types of antenna that can be used to catch up electromagnetic waves easily from the atmosphere. However, the choice of antenna depends on so many factors among which include impedance matching, receptivity, and amount of energy transferable. Consequently, a dipole antenna was chosen because it has high receptivity, and can be easily matched to the RF circuit if well designed.

### 3.2.2 RF receiver prototype

Fig.3.9 shows the circuit diagram of the designed prototype for the RF energy conversion circuit.

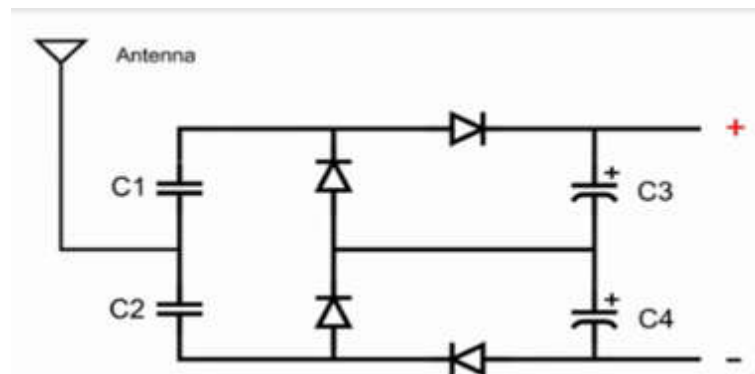


Figure. 6: The RF circuit

The RF receiver prototype was built using the circuit in Figure 6. The connection was first done on breadboard. After the prototype circuit had been built, the dipole antenna was then connected to the circuit using BNC connector to ensure perfect impedance matching. Hence, maximum energy was transferred from the antenna to the RF circuit. A voltage multiplier was used to amplify the voltage at the output of the RF signal.

### 3.3 HYBRIDIZATION OF THE PIEZOS ENERGY HARVESTER AND THE RF ENERGY HARVESTER

The two energy harvesters were hybridized by cascading them through a DC-DC converter for stabilization and amplification. The block diagram in Figure 3 shows the hybridized energy harvester. The following procedures were followed in fabricating the hybridized energy harvester.

- a) The transparent plastic was measured and cut according to the size of the circuits to be housed.
- b) The cut plastics were drilled in order to accommodate screws.
- c) The plastics were then fastened together to conveniently accommodate each of the circuits to be housed.
- d) The circuits were fastened to the casing with the aid of bolts and nuts.
- e) An HDMI plank was cut according to the size of the foot mat.
- f) The foot mat having the piezos was then placed on the center plank which is the exactly its size.
- g) Another plank was then placed below and above the initial plank.
- h) Both were then fastened together with the aid of bolts and nuts.
- i) Springs were inserted in each of the bolts to allow easy to-and-fro movement of the uppermost plank to the bottom plank as pressure or forced is being applied to it.

The prototype of the hybridized energy harvester is shown in Figure 7.



*Figure. 7: Hybridised Energy Harvester Foot Mat*

#### **4. RESULTS AND DISCUSSION**

In this section, the hybridised energy harvester foot mat is tested. The output voltage and current of the harvester were measured and recorded. It was then used to power few light-emitting diodes (LEDS) and to charge mobile phones. The maximum output voltage for the prototype RF energy harvester was measured as 32.2mV. Meanwhile, the hybridized energy harvester's output voltage and current are 6V and 1.12A respectively.

#### **5. CONCLUSION**

In this work, we developed a hybridised energy harvester using piezo electric and RF in form of foot mat, which could be used to power low energy consuming devices.

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