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A MICRO-POWER GENERATION FROM RAIN SHOWER UTILIZING PZT AND PVDT PIEZOELECTRIC TRANSDUCER

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ABSTRACT

As the fossil resources are at risk of extinction, many efforts are being introduced to produce electrical energy. Micro-electrification by utilizing the energy from vibration has become an alternative way to generate electricity. It is through a device with sub-micron-scale dimension sub-micron-scale dimension. This work focus to generate electricity with the utilization of the off-the-shelf piezoelectric transducers; Polyvinylidene Fluoride (PVDF) and Lead Zirconate Titanate (PZT) under different rain shower density. With the three different flow rate of an artificial rain shower, it is able to generate maximum power of 2.4×10^{-6}Watt and 27×10^{-6}Watt for PVDF and PZT, respectively. However, the energy is significantly influenced by the rectifier circuit. This paper presents the performance of the power generation from raindrop using piezoelectric transducers available in the open market.

Keywords: alternative energy, piezoelectric transducer, power generation.

INTRODUCTION

There are many ways to harvest energy from natural resources for electrification. A large scale Solar Photovoltaics, for instance, has become mainstream in electrification for few decades. Likewise, energy harvesting from rainfall has gained huge interest among researchers to produce electricity. The employment of micro-hydro technique was one of the earliest methods that being adopted by researchers to produced electric energy from the rainfall. For example, Martin and Shrivastava used rainfall source from rooftop to generate electrical energy [1]. The Rooftop Hydroelectric Generation project which stores rainwater at the top of the building flows through the pipe and rotate turbines that connected to a generator. Additionally, the excess storage of rain water on the underground will be used for other uses such as plants and gardens. The design of the micro-hydroelectric power generation is improved by adding the vacuum to pump the water back to the above storage during non-rainy days. The system involves storage tanks, pipe network, and flow control valves. The area with highest rain density could generate power up to 5kW.

Another means for electrification from rainfall is by adopting a vibration and bending based technique via piezoelectric materials. The piezoelectric materials are used as a mechanism to transfer ambient motion i.e. vibration, into an electric energy [2]. Apart of this, the electrification also realized by bending the piezo plates to gain its physical strain and oscillation characteristic [3] [4]. In real rainfall, the raindrops' impact has a different position of the piezoelectric plates, therefore powering devices require a size that is suitable for the application, sufficient power and extended lifetime using permanent and ubiquitous energy sources [5] [6]. Recent literature reveals this system has been studied by many researchers. For instance, Wong *et al* has reported his very own lab scale piezoelectric energy harvesting test bench. The work simulated the various type of rain condition to produce total energy in the range of 38×10^{-6}Joule to 114×10^{-6}Joule [6]. A year before that, Warude [7] and friends had done a simulation using ANSYS structural analysis method to analyze the data collected from the experimental setup. It produced 2.66×10^{-20} up to 4.55×10^{-12} J energy under the designated technique.

This study presents an alternative method for electrification i.e. via Piezoelectric Polyvinylidene Fluoride (PVDF) and Lead Zirconate Titanate (PZT) devices. The observation of its performance under three different density of raindrops from the test jig with distance 1.5 meters shows that the system could generate up to 2.4×10^{-6}Watt and 27×10^{-6} Watt for PVDF and PZT, respectively.The experiment reveals the potential of electricity generation from the natural sources, in this case, raindrops.

PIEZOELECTRICITY

Ceramic materials have an attribute of piezoelectricity. It was found by Pierre and Jacques Curie in 1880 [8]. Piezoelectric can be described as the capability of particular materials to produce electric potential difference when subjected to mechanical stress. DNA, enamel, dentin, and silk are some examples of the existing natural piezoelectric materials. Material such as quartz, ZnO, synthetic crystalline, sodium potassium is some other material example that exhibits the property of piezoelectric. Among them, Polyvinylidene Fluoride (PVDF) and Lead Zirconate Titanate (PZT) are the common types of piezo materials uses for electrification. According to [7], the acceptable properties of PVDF in generates electricity is slightly lower compared to PZT due to the fact that there is no lead element in the PVDF. However, PVDF is much more flexible, light, tough and

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non-toxic. The relation of the material and the voltage generated in the voltage mode from the devices due to small strain (or stress) can be described by the following equation,

$$V_o = g_{3n} X_n t \quad (1)$$

Where 'g' is the piezoelectric coefficient, 'V' is the maximum voltage generated, 'X_n' is the applied stress in the relevant direction, 't' is the thickness of the piezoelectric material. On the other hand, in charge mode, the generated charge density is given by:

$$D = \frac{Q}{A} = d_{3n} X_n \,, n = 1,2, or\ 3 \quad (2)$$

Where,
$D \quad = charge\ density\ developed$
$Q \quad = charge\ developed$
$A \quad = conductive\ electrode\ area$
$d_{3n} = appropiate\ piezoelectric\ coefficient$
$for\ the\ axis\ of\ applied\ stress\ or\ strain$
$n \quad = mechanical\ axis$
$X_n \quad = stress\ applied\ in\ the\ particular\ direction$

The most common used coefficient of the piezoelectric is the d_{mn}, and g_{3n} as aforementioned [9]. It has been reported that harvestable energy can be calculated by considering the generated voltage and its corresponding current. The relationship can be addressed by the following well-known equation;

$$P_{max} = V_o I \quad (3)$$

Where P is power in unit Watt (W), V_o is the generated voltage by the piezo materials in unit volt (V) and I is the corresponding current in unit ampere (A). The general overview of an electrification via piezoelectric material can be best described by the following diagram;

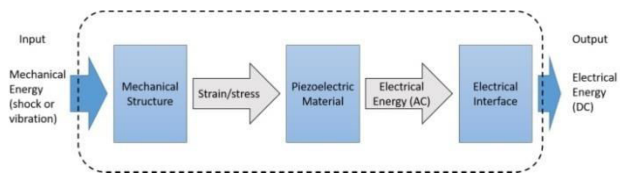

Figure-1. General electrification diagram of piezoelectric devices.

The output power of the electrification by the piezo element is given by:

$$P_{out} = \eta_{collision} \cdot \eta_{piezo} \cdot \eta_{rectifier} \cdot P_{max} \quad (4)$$

As illustrated in Figure 1, practically, it is necessary to have a converter to charge a battery or to feed to an electronic device[10]. An AC to DC converter or simply a rectifier is the one suited for that job. A full bridge rectifier consists of four diodes and a capacitor with load resistor parallel-connected to it is the simplest converter design to get a DC output from the AC input generated by the piezoelectric transducers. The energy stored by the capacitor in the circuit is given by:

$$E_c = \frac{1}{2} C_r V_L^2 \quad (5)$$

From the equation, it is clearly seen that the energy in the capacitor is directly proportional to its capacitance, C_r.

CANTILEVER CONFIGURATION

As mentioned in the previous section, ceramic-based piezoelectric i.e PZT and polymer based piezoelectric i.e. PVDF are the common and widely used material for energy harvesting. The voltage difference is generated across the piezo transducer terminal once it is deformed or stress physically. The behavior can be model mathematically by the following equation[11]:

$$S = s^E T + d_t E \quad (6)$$

$$D = d_t T + \epsilon^T E \quad (7)$$

Where S is the mechanical stress, T is applied mechanical stress and, D is electrical displacement. While s^E is matrix of elasticity under constant electric field, d is piezoelectric coefficient matrix and $\epsilon^T$is permittivity matrix.

A cantilever configuration is one of the promising piezoelectric structure to acquire high output power. This is because a large amount of strain can be applied to the elements under vibration condition [12]. Unimorph, bimorph series and parallel are three types of the cantileverbeam of the piezoelectric generator. The diversity of the unimorph and bimorph can be visualized in Figure-2.

Mode-31 and mode-33 are the commonly exploited coupling mode in energy harvesting with cantilever configuration. Mode-31 is realized when the force is applied in a perpendicular direction towards the poling direction, while mode-33 is obtained with the force coming from both sides of the piezo material like a sandwich [7]. In this experiment, unimorph with mode-31 is been chose due to its compatibility in energy harvesting. The maximization of the output power of the cantilever piezoelectric energy harvester can be achieved by operates it at its natural resonance frequency. Therefore, it is essential to find the best tuning for the natural frequency.

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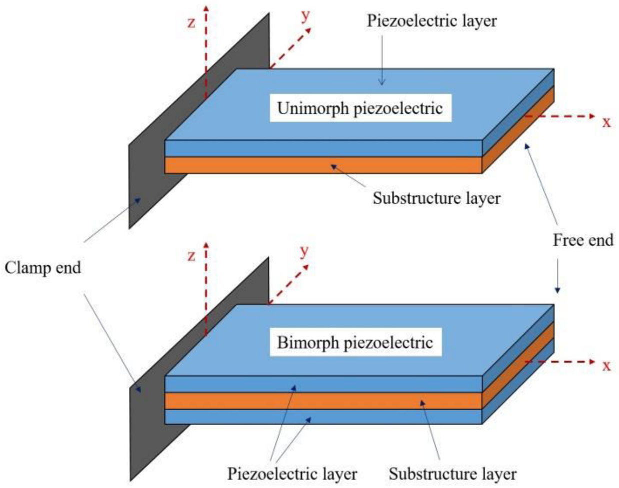

Figure-2. Unimorph and bimorph piezoelectric cantilever structure.

The undamped resonance frequency for the cantilever piezoelectric material in transverse vibration is given by the following mathematical equation:

$$f_o = \frac{1}{2\pi}\sqrt{\frac{k_{eq}}{m_{eq}}} \tag{8}$$

where the k_{eq} is the equivalent spring rate and m_{eq} is the equivalent mass. k_{eq} and m_{eq} can be further extended to the following equations:

$$k_{eq} = \sqrt{\frac{3YI}{L^3}} \tag{9}$$

$$m_{eq} = \sqrt{\left(\frac{33}{140}\right)mL + M_t} \tag{10}$$

where *YI* and *L*are the flexural rigidity and the length of the beam, respectively. While *m* is the mass per unit length and M_t is the tip mass. In addition, 33/140 (23.5%) is the area where the mass of the beam participates in the motion. Based on the equation, it can be concluded that the resonance frequency can be tuned by changing the dimension of the cantilever [12].

EXPERIMENT SETUP

The transducers used in the experiment were off-the-shelf Mini Sense 100 PVDF type [13] and Piezo Element Ceramic PZT type [14]. It can be seen in Figure-3.

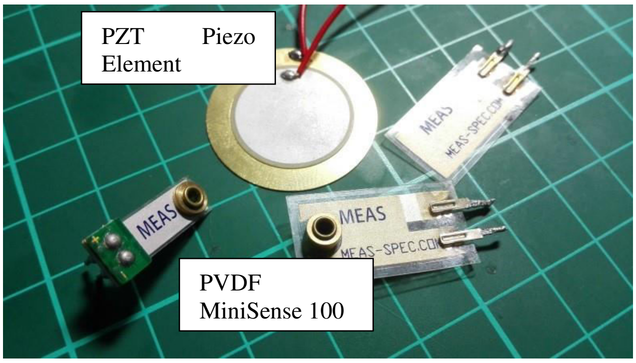

Figure-3. PZT and PVDF piezoelectric transducers.

Both transducers have been mounted in the suitable cases and then it will be exposed to artificial and actual rain. Two cantilever configurations have been used for measurement purpose i.e. single edge bound and circle edge bound. PVDF module was set as for cantilever single edge approach. Once the rain drops hit the transducers' edge it will generate an electrical potential due to bending stress applied to it. On the other hand, circle bound configuration has been applied to PZT transducer on which the raindrop knockout on the transducer's surface. Hence, it generates an electrical potential at the electrode terminal of the transducer. Figure-4 illustrated the devoted cantilever configuration for the experiment.

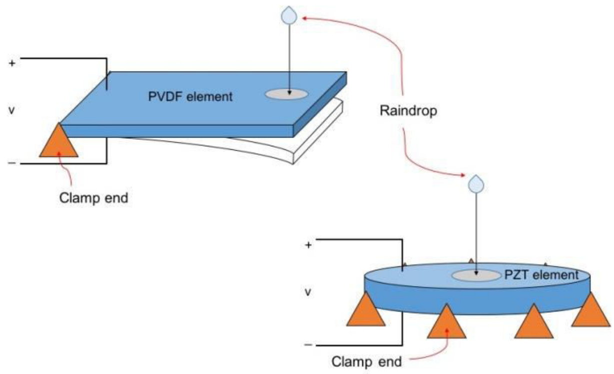

Figure-4. Piezoelectric cantilever, one edge bound (left), circle bound edge (right).

The developed modules and its relevant circuitry are depicted in Figure-5 and Figure-6 respectively. The PVDF harvester module was built using ten pieces of the piezo transducer which connected in parallel. Each transducer is connected to a 33nF non-polar capacitor and 1N4001 diode rectifier bridge as illustrated in Figure-7. Similarly, the PZT module also assembled with ten pieces of the piezo transducer and connected to the rectifier circuit.

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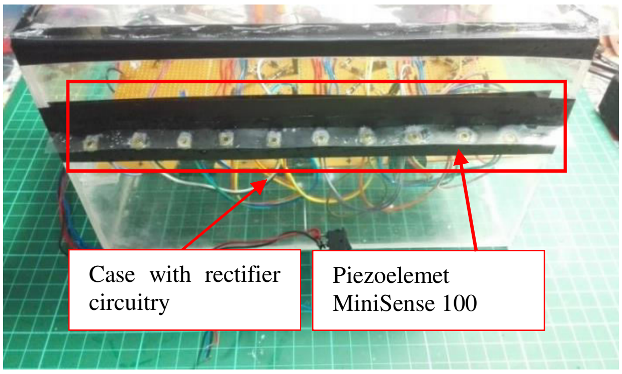

Figure-5. PVDF module.

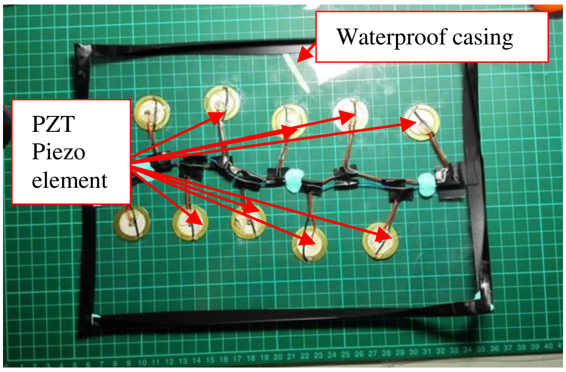

Figure-6. PZT module.

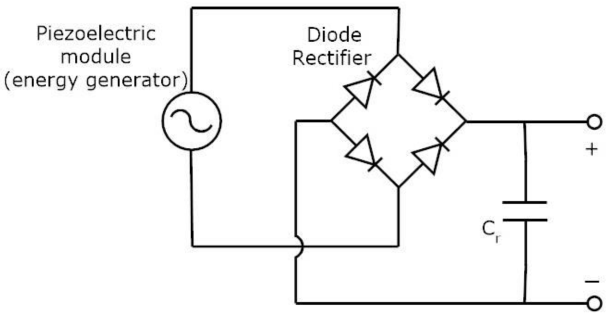

Figure-7. Basic circuitry of the experimental modules.

In order to see the potential of the system, measurement was taken under an artificial rain setup. Imitation of the rain was done through the water shower which is set 1.5 meters height from the piezo module. The experiment employed three different artificial rainfall density i.e. small, medium and heavy; approximately 2psi, 8psi and 14psi, respectively within 50 seconds interval. The measurement of current and voltage produced by each module was recorded in every 10 seconds.

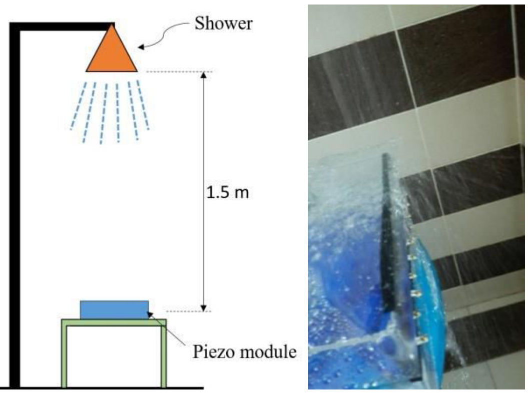

Figure-8. PVDF module testing under water shower. The height is 1.5m between the module and shower.

RESULT AND DISCUSSIONS

The experiment is set to simulate an anticipated potential electrification result via both types of piezoelectric transducers. An output power generated by PVDF modules under medium shower density shows lower in volume ($1.3x10^{-6}$ W) compared with the PZT module ($19x10^{-6}$W). It generates $246x10^{-9}$J and $76x10^{-9}$ J in average for PVDF and PZT respectively. PVDF also produced slightly low volume in output power ($2.4x10^{-6}$W) compared with the PZT ($27x10^{-6}$W) under the maximum shower density. However, a significantly low volume of power is generated under small density shower, $0.014x10^{-6}$W and $0.059x10^{-6}$W for PVDF and PZT, respectively. Despite PZT's higher output power, with the employed circuitry, it provides less energy compared to PVDF at the output terminal. The amount of energy collected proportionally depends on the capacitor value used in the rectifier. Table-1 summarized the power and energy generated by the PVDF and PZT under medium and maximum shower density.

Table-1. An energy produced from the PVDF and PZT piezo element with the implementation of full-bridge rectifier utilizing 33nF capacitor.

	Shower density	**Energy** (nJ) ($0.5*C_r*V^2$)
PVDF	Mid	246
	Max	402
PZT	Mid	76
	Max	129

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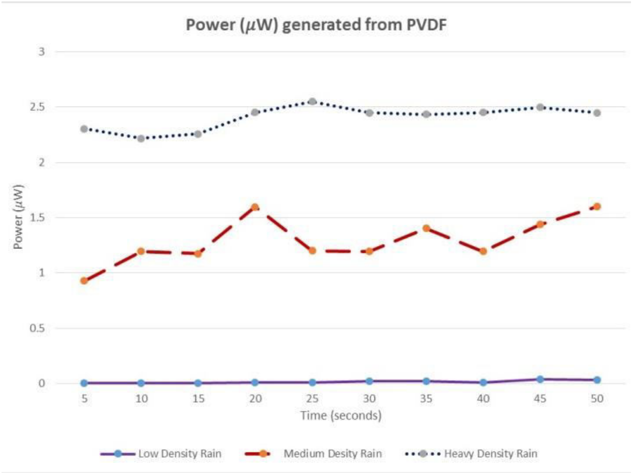

Figure-9. Power generated by PVDF piezoelectric module under three different shower densities.

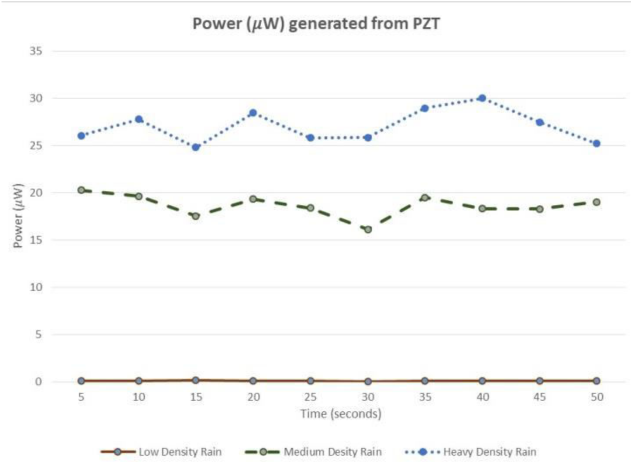

Figure-10. Power generated by PZT piezoelectric module under three different shower density.

As the experimental setup was done using off the shelf piezo transducer, the dimension of the element is fixed. Thus, the output of the transducer is closely depending on its dimension in order to generate maximum resonance frequency. Therefore, in this work, the output voltage and current are limited based on the specification of the transducer. Additionally, the used of full bridge rectifier reduced its efficiency to generate maximum output power. However, with the specific designed of piezo element and its conversion circuit, the output power can be optimized accordingly.

CONCLUSIONS

This study shows that the micro-electrification from raindrop can be realized by using piezoelectric transducer i.e. PVDF and PZT. It can be observed from the measurement and the power generated. Three different setups with different shower density gives a different result. Higher density shower generates higher output power compared the lower one. Under the experimental work, it is also discovered that PZT produced higher output power compared to the PVDF. However, with the used of the rectifier circuit, the energy is significantly influenced by the capacitor value. The performance shall be improved by imposing a high-efficiency rectifier and optimized piezoelectric transducer.

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