# Piezoelectric Model of Water Drop Low Voltage Harvester

Azrul Mahfurdz
Politeknik Sultan Hj Ahmad Shah (POLISAS)
azrulabm@polisas.edu.my

Saifuddin Semail
Politeknik Ibrahim Sultan (PIS)
saifuddin@pis.edu.my

Sunardi Sasmowiyono
Universitas Ahmad Dahlan (UAD) Yogyakarta, Indonesia
sunargm@yahoo.com

**Abstract**

This research proposes the low voltage measurement from piezoelectric transducer. The vibration source is The acquired from water drop impact for different distance. A Strip chart used to record voltage signal from piezoelectric at 100 Hz sampling rate. The voltage for each sample was saving in excel format and analysed in MATLAB software. The voltage generated has been compared and analysed for three type of piezoelectric transducer from polyvinylidene fluoride type (PVDF). Based on the experiment and analysis, it discovered that transducer equipped with ring mass generate high amplitude voltage compare than other type PVDF. The finding also showed PVDF equipped with mass ring oscillated more amplitude voltage compare than PVDF without mass ring. The voltage comparison between three type of PVDF at different height discovered that there are significant different for each type. The more height increase the more force impact given and will change the voltage generated by PVDF transducer. Other than that, the result also showed the transducer dimension will changed the inductive and resistive value and can influenced voltage generated from transducer.

**Keywords**: Piezoelectric, low voltage, waterdrop impact, energy harvester

## 1. Introduction

The high electricity consumption causes more amount of energy generated in order to meet the needs of users. This led to rising demand for fossil fuels as fuel in electric power stations. Furthermore, it also increases the electricity tariffs and billing electric energy services which is indeed be a burden to the public. The use of renewable resources is seen as an alternative way to replace the existing energy sources.

One of the new method promises is through the conversion of ambient vibrations into electrical energy through a piezoelectric device. This energy can be stored and used to power up electrical and electronics devices (Jedol Dayou et al, 2009). An energy harvesting from piezoelectric has growing rapidly over the last decade. The focused in this research field is due to the reduced power requirement of small electronic device, such as the micro sensor networks used for monitoring and self-charging applications (Alper Erturk and Daniel, 2011).

The piezoelectric is discovered in 1880 by Pierre and Jacques Curie. They studied on the generation of electrical charge by crystals such as Quartz, tourmaline, and Rochelle salt. The term piezoelectricity was first introduced by W. Hankel based on the thermodynamics principles (Jordan and Ounaies, 2001).

The piezoelectric device has been design in many forms depending on to their application. The device can be found in many forms, including piezoceramic, single crystal, thin film, screen-printable thick film, and polymeric material (Beeby et al, 2006). The most common types of piezoelectric material being used are polyvinylidene fluoride (PVDF) and lead zirconate titanate (PZT) (Wong et al, 2014). The comparison between two type material piezoelectric ceramic Lead Zirconate Titanate (PZT) and polyvinylidene difluoride (PVDF) showed that PVDF has a lower cost than PZT, PVDF is not toxic, while PZT is toxic, and PVDF makes available to the electrodes higher power (Vioala et al, 2013).

The piezo technology has been widely applied in many applications, for example it has been used to convert stress from vehicle. The transducer is embedded beneath the road and will convert energy while vehicle pass them (Aqsa Abbasi, 2013). In addition, it has been design as micro electromechanical systems which supplies energy to the wireless sensor network (Nechibvute et al, 2012).

The power conversion using piezoelectric is very wide and expended to convert sound wave to electrical power, for example energy also can convert from aircraft noise such as aerodynamic noise, engine and other mechanical noise (Gupta et al, 2013).The comparison vibration from three source which is construction pilling, hydraulic pump and train wheel discovered that vibration from train wheel give high voltage (Arnab et al, 2014).

Most previous studies on piezoelectric energy harvesting have concentrated on machine and human activity which is involved heavy vibration. Recently, there are effort to generate energy from water drop and rain drop. The voltage produce by single PVDF and two parallel PVDF when exposed to the rain drop showed that single PVDF produced high voltage value compare than double PVDF (Viola et al, 2013). Besides that, study on a piezoelectric harvester of rainfall energy model demonstrated that by increasing height there is an increase in the maximum value of the voltage produced by the drop (Viola et al, 2014). The other factor also can influence the voltage value produce by piezoelectric is water drop size and volume (Emma and Antoinette, 2015; Aashay Tinaikar, 2013).

The literature previously reported that the single drop of water hitting the piezoelectric plates generates voltages less than the tens of volts (Viola et al, 2014). Therefore, a force from water drop can be use as vibration source for the piezoelectric to convert mechanical energy to electrical energy.

The investigation of vibration effect from water drop previously only involved one size of piezoelectric and has been tested without weighting element. In this study, there are two factor will be investigated which is vibration signal pattern between PVDF design with and without mass. The second factor is to investigate how the size of piezoelectric transducer can change the voltage value. The experimental finding of this study considered important and can be used to design small supplies energy and self-charging device.

## 2. Piezoelectric Energy Harvesting and Equivalent Model

Piezoelectric materials can be used as mechanisms to transfer mechanical energy, usually ambient vibration, into electrical energy that can be stored and used to power other devices. Basically, source of vibration can be come from mechanical force. However, it also can generate from natural force such as wind, rain and atmospheric noise. Generally, the alternating voltage produce by piezoelectric material will be fed to a bridge rectifier and store in rechargeable cell or capacitor as shown in Figure 1.

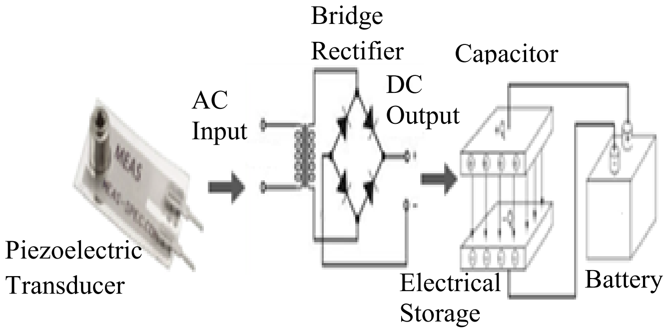


Figure 1. Piezoelectric Energy Harvester System

The method of modelling piezoelectric vibration reaction consist two main parts which is both the mechanical and electrical portion. The mechanical part is representing vibration force and electrical part is represent the voltages produce by piezoelectric. The method of modeling piezoelectric elements such that system equations for PVDF type has been discuss comprehensively by many researchers. The easy concept to understand piezoelectric effect is by modelling the device as a transformer (Viola et al, 2014; Roundy and Wright, 2004) as shown in Figure 2.

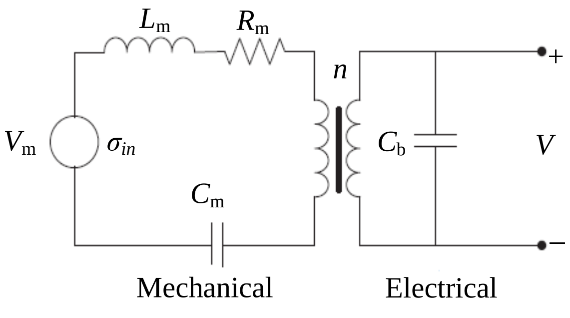


Figure 2. Circuit Representations Of Mechanical And Electrical Portions

In the mechanical portion, $L_m$ represents the equivalent mass and the inertia of the vibrating mass, $R_m$ represents the mechanical damping, $C_m$ represents the mechanical stiffness, stress generator $\sigma_{in}$ is due to external mechanical vibration that represents the stress developed as a result of the vibrations source. $n$ represents the equivalent turns ratio of the transformer. $C_b$ is the capacitance of the piezoelectric bender. $V$ is the voltage generated by

piezoelectric transducer. The variable source on the mechanical side of the circuit is stress, $\sigma$ (analogous to voltage in electrical circuit), and the variable flow is strain rate $\dot{S}$ (analogous to current in electrical circuit) [14].
The equation from mechanical portion can be determined using Kirchhoff's voltage law (KVL) and Kirchhoff's current law (KCL). By applying KVL which stated that the total voltage in close loop circuit is zero, the voltage equation then expressed in equation (1). The equivalent currents at node 1 in Figureure 2 yields the expression in equation (2).

$$\sigma_{in} - Lm\dot{S} - R_b\dot{S} - \dot{S}C_m - V_m = 0 \quad (1)$$

$$i = C\text{b}\, V \quad (2)$$

The relationship between electromechanical couplings then can write as transformer constitutive equation and can be express as

$$V_m = n_v\, V_e \quad (3)$$

The PVDF transducer has been studied and value of inductance and resistance has been proposed in the electromechanical model [11]. The inductive and resistance value can be represent as

$$L_m = k_1\, k_2\, m \quad (4)$$

$$R_m = k_1\, k_2\, b_m \quad (5)$$

where $m$ is the mass of the water drop, $b_m$ is a traditional mechanical damping, $k_1$ and $k_2$ are geometrical coefficient, given by:

$$\text{k1} = \text{b}(2\text{L}_\text{b}\text{-L}_\text{e})/2I(\text{b}) \quad (6)$$

$$\text{k2} = 2\text{L}_\text{b}^3/3\text{b}(2\text{L}_\text{b}\text{-L}_\text{e}) \quad (7)$$

The voltage value generated by piezoelectric is dependent on dimension of transducer. The moment of inertia relative to a homogeneous mass is represent by I(b) and the other quantities dimension as presented in Figure 3.The change of geometrical coefficient will change the inductance and resistance and further can affect the amount of voltage across transducer.

## 3. Methodology

In this study three category of piezoelectric transducer have been used which is from polyvinylidene difluoride type (PVDF- LDTM-028K) as shown in Figure 3. LDTM-028K is a flexible component comprising a 28 µm thick piezoelectric PVDF polymer film with screen-printed, laminated to a 0.125 mm polyester substrate, and fitted with two crimped contacts. As the piezo film is displaced from the mechanical neutral axis, bending creates very high strain within the piezopolymer and therefore high voltages are generated.

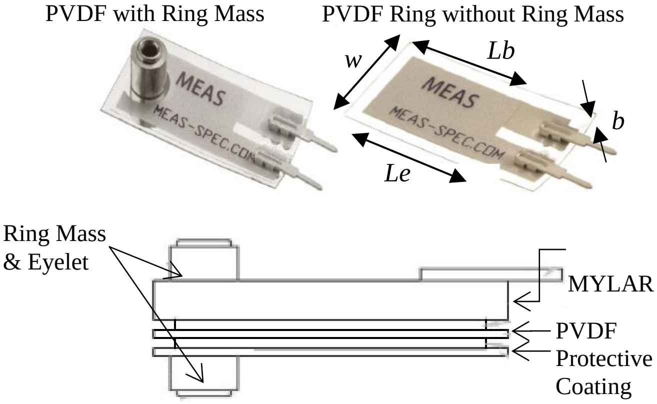


Figure 3. LDTM-028K Polyvinylidene Difluoride (PVDF)

The detail PVDF category and dimension size involved in this study has been shown in Table 1. The selected piezoelectric was made to try to provide a comprehensive overview of the possibility to extract energy from water drop.

Table 1. Type of Polyvinylidene difluoride (PVDF)

| Material | Type | Dimension |
|---|---|---|
| Polyvinylidene difluoride (PVDF) (LDT0-028K) | Type A : PVDF with Ring Mass | 25mm x 13mm |
| Polyvinylidene difluoride (PVDF) (LDT0-028K) | Type B: PVDF without Ring Mass | 25mm x 13mm |
| Polyvinylidene difluoride (PVDF) (Minisense 100) | Type C: PVDF with Ring Mass | 17mm x 6mm |

The PVDF sensor was connected to digital oscilloscope to confirm the impulse response produced by the sensor. The sample of impulse voltage then was recorded to computer using high speed input device (Measurement Computing-USB1208HS). The amplitude of voltage was read in strip chart graph using TracerDAQ software provided by Measurement Computing. The impulse response for each sample was saving in excel format and analysed in MATLAB software. The experiment setup in this study is shown in Figure 4 and Figure 5.

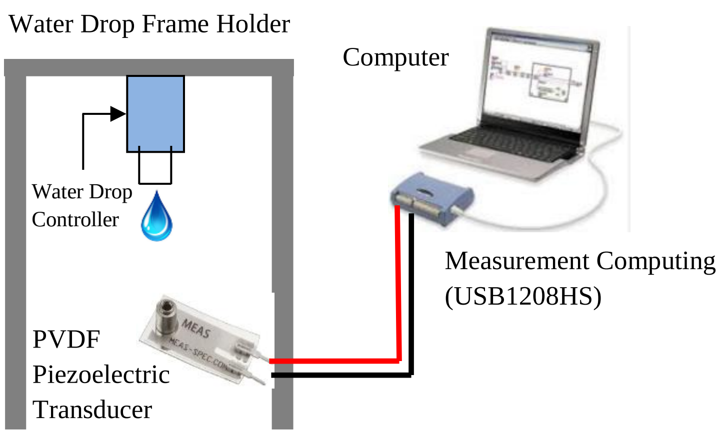


Figure 4. Piezoelectric Energy Harvesters Experiment Setup

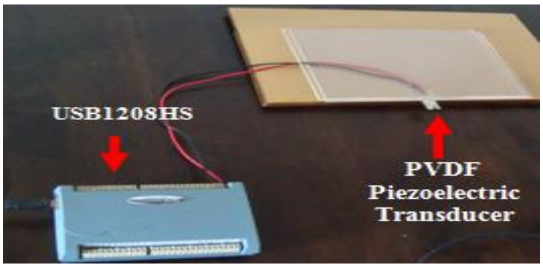


Figure 5. Piezoelectric Transducer Position

The voltage produce by each type of piezoelectric device was investigated when water fall on the surface transducer. The voltage effect has been observed by change the height of water drop. In this study, the size of water drop is constant for each fall-out. The average diameter of water drop is 0.4 cm, which is has been controlled manually using water drop valve controller.

## 4. Results and Discussion

The voltage across three different PVDF has been recorded using strip chart graph provided by Measurement Computing. The diameter and speed of each water drop was controlled using water valve controller. In this experiment, the vibration pattern was observed for certain distances (90 cm, 100 cm, 110 cm and 120 cm) which is to investigate the magnitude change for each water drop impact. Figure 6 demonstrated the vibration pattern or three type of PVDF at 90 cm height.

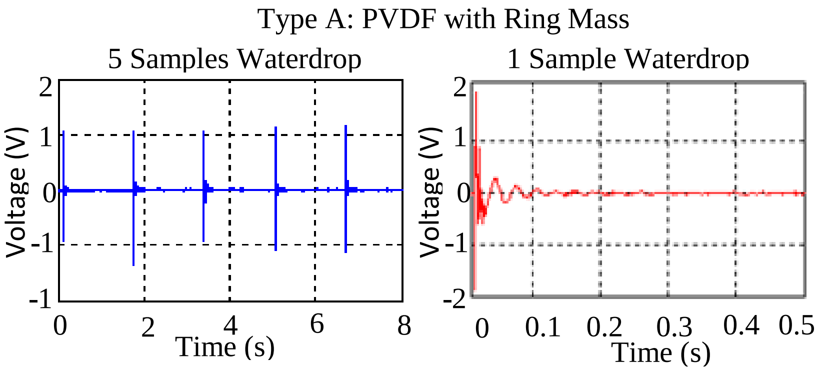


Figure 6(a). Vibration Pattern Of Pvdf With Ring Mass

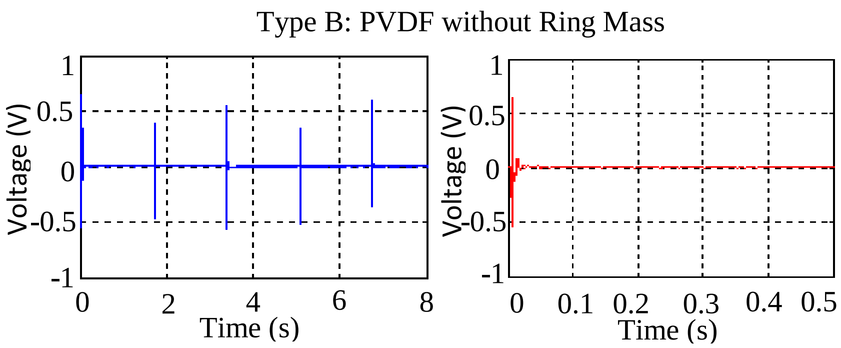


Figure 6(b). Vibration Pattern Of Pvdf Without Ring Mass

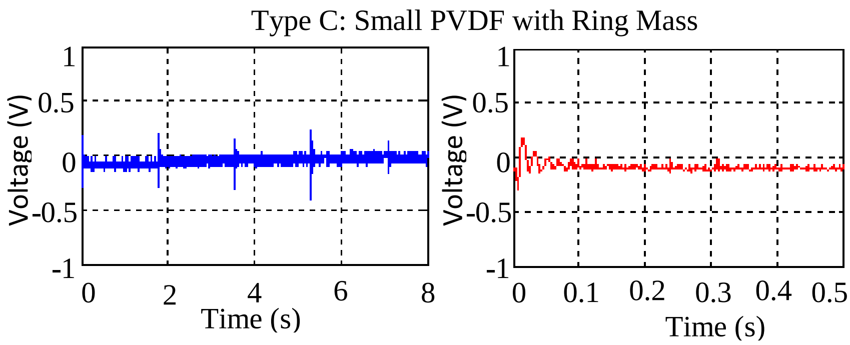


Figure 6(c). Vibration Pattern Of Small Pvdf With Ring Mass

Based on the result, it discovered that transducer equipped with ring mass generate high excitation compare than other type PVDF. The result also showed PVDF equipped with mass ring oscillated more amplitude voltage compare than PVDF without mass ring. In other word, when piezoelectric received force from water drop impact the PVDF with mass produce more cycle compare than transducer without mass.

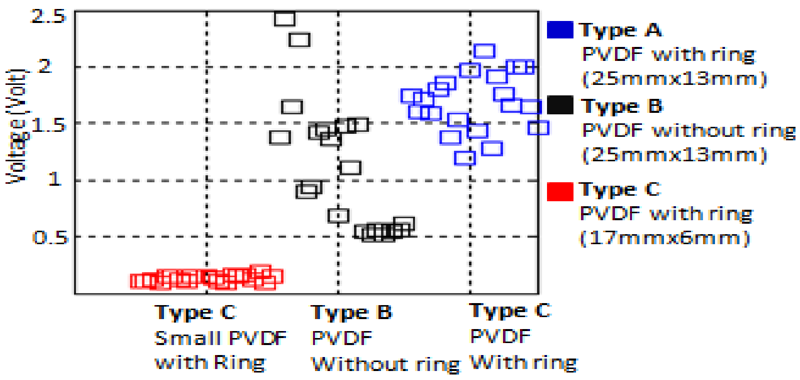


Figure 7. Average Voltage Samples At 90 Cm Height

Figure 7 demonstrated the samples of peak to peak voltage produced when water drop from 90 cm height. The scatter diagram showed the value obtained from PVDF with mass for both size is more consistent compare than PVDF without mass. The voltage range produced by 25 mm x 13 mm PVDF with mass ring is 1.2 to 2.2 Volts and for size 17 mm x 6 mm is 0.10 to 0.15 Volts. Meanwhile the value obtained from PVDF without mass is more scatter with voltage range is between 0.5 to 2.5 Volts.
The voltage comparison between three type of PVDF at different height (Figure 8) discovered that there are significant different for each type. The average peak to peak value increase when the height of water drop changed. The more height increase the more force impact given and the voltage impulse produced by PVDF transducer.

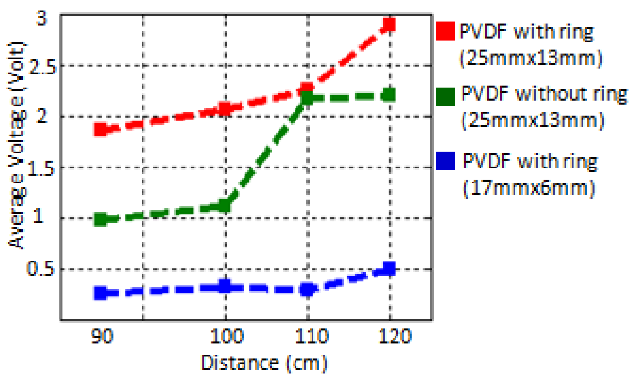


Figure 8. Average Voltage Generated From Different Pvdf

## 5. Conclusions

The voltage generated from piezoelectric transducer was measured for three type of PVDF. The voltage change has been analysed when transducer received force impact from water drop. The comparison voltage generated from PVDF showed that there is significant different for three type of PVDF transducer. The voltage generated from PVDF with mass ring is higher compare than PVDF without mass ring. In addition, the finding also discovered that sizes PVDF also can influenced the voltage value. In other word, the geometry dimension is one of the important factors can influenced voltage generated from transducer. The changing of geometry dimension will change the value of inductive ($L_m$) and resistance ($R_m$) in equation 4 and 5, where finally can affect the value of voltage across the PVDF transducer. In this experiment, the voltage generated was investigated only at certain height and only involved three type of PVDF. Therefore, further research is proposed to be conduct for different height of water drop and different size of transducer which is to find the inductive and resistance effect in electromechanical model.

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