Energy harvesting from raindrop impacts using piezoelectric devices

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Introduction

Piezoelectric materials have been used as a means of transforming externally available vibrations into electrical energy that can be used to power devices and potentially store that energy. Raindrop energy harvesting techniques using piezoelectric materials simply convert the impact energy and subsequent mechanical vibration of the device into electricity. Energy harvesting from the impact of raindrops has been gaining significant research interest over recent years but the potential still has not been fully unlocked. The energy output depends mainly on the mass of the droplet, the velocity and the mechanism of impact at which it strikes the harvesting device.

Methodology

A commercially available piezoelectric sensor by Pro-Wave (FS-2513P) was used in this study due to its favorable properties. Raindrops were artificially replicated in the laboratory and set to produce drops at a constant size and rate. Various experiments were conducted over single or multiple devices at various heights, angles and surface areas.

Single event

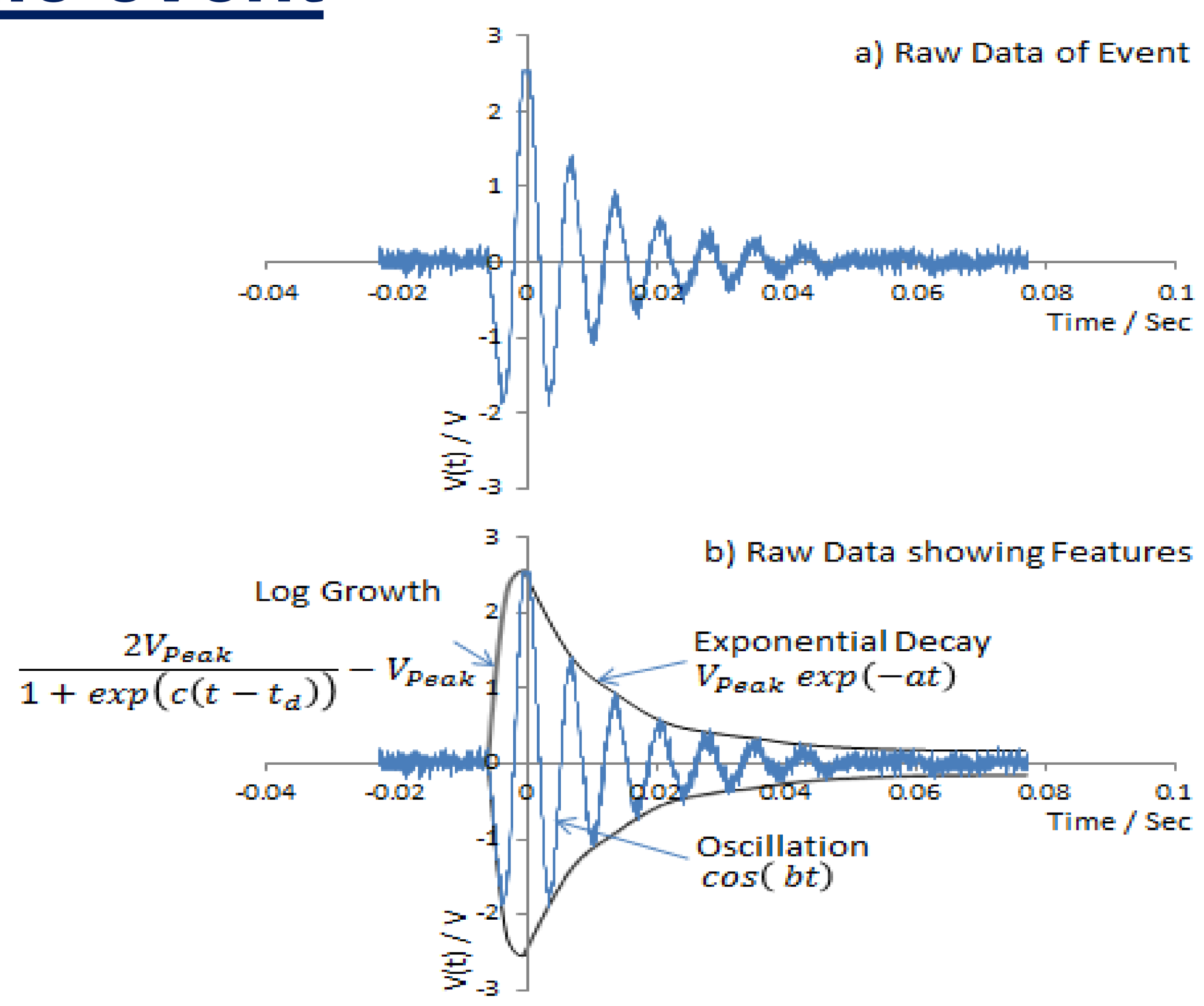

Fig 1: Voltage output of harvester for one event

An oscillating profile is shown which consists of two stages as the event evolves with time. These stages are; "log growth" stage as the voltage grows to a maximum followed by the "exponential decay" stage as the voltage decreases to zero.

$$V(t) = \left(\frac{2V_{Peak}}{1+exp(c(t-t_d))} - V_{Peak}\right) cos(\ et)$$

Peak power and energy:

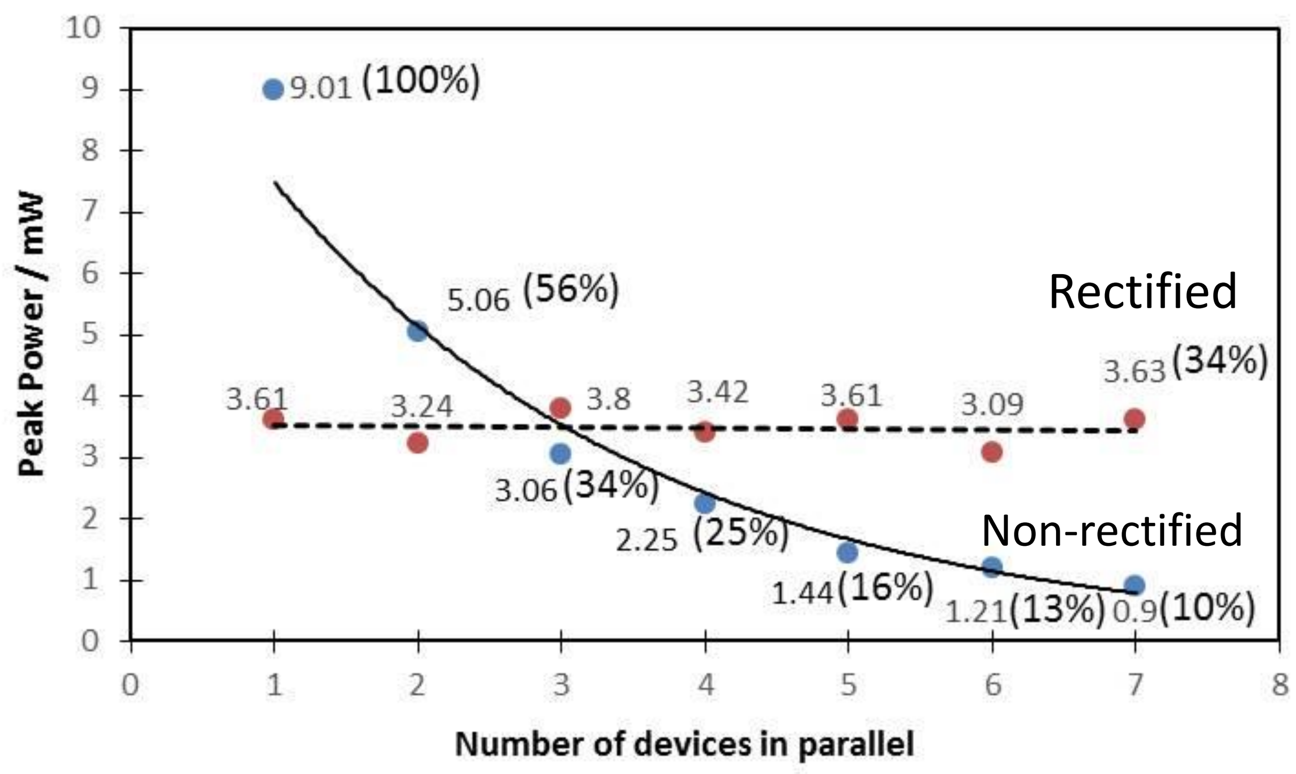

Fig 3: Peak power of the module (with multiple devices)

Peak power of module is calculated for devices connected in parallel. The output voltage is a function of n devices and is empirically modelled as:

$$V_{em}(n) = 0.9117n^{-0.629}$$

The energy captured from the impact mechanism E_0 can be found by:

$$V_{stm}(n) = \left(\frac{E_0}{t_d}\right)^{0.5} \left(\frac{1}{R_{load}} + \frac{n}{R_0}\right)^{-0.5}$$

Harvester array

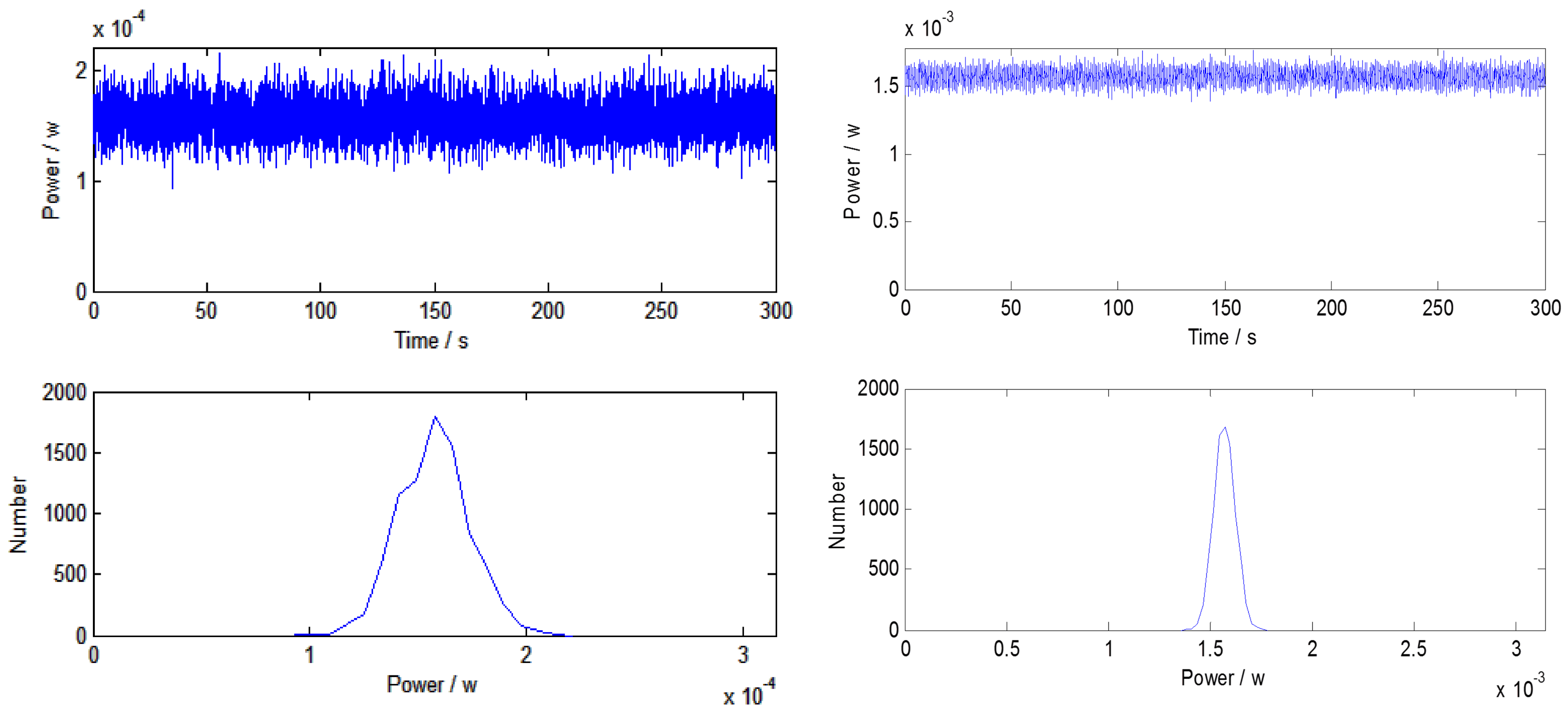

Fig 2: Mean power from harvesting model

The equation below is used to model the behaviour of a unit harvester, based on the empirical data acquired in this study, and implemented in an algorithm to model a harvester array. A numerical approach is used for multiple units in an array of defined size for a rainstorm of particular duration and quantity. The power output is "noisy" due to the random nature of rainfall. With an increase in the size of the array, the noise to signal ratio is reduced significantly.

$$P_{mean} = M_R^2\ R^{-0.2572}\ v^2\ \tau$$

Conclusion

- Droplet impact stage (log growth) has a significant contribution to the overall power output of a single device.
- A model has been developed which takes the empirical data for the device during a single event and uses this for an array of harvesters.
- The overall efficiency of the module decreases by adding more devices as they are a source of power loss.
- A technique is found to separate the efficiency of the impact mechanism as the droplet interacts with the device and the efficiency of the mechano-electric conversion mechanism due to internal losses in the device.

Future Work

- Analysis and behavior of the device/module under real rain shower.
- Increasing the output of the device by improving conversion efficiency (voltage multiplier)

References

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2) M. A. Ilyas and J. Swingler, "Towards a prototype for Piezoelectric energy harvesting from raindrop impacts ,"Energy , vol. 125, no. 1, pp. 716-725, 2017

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