

# Volume-Effect Based High-Performance Tubular Nanogenerators for Flowing Water Kinetic Energy Harvesting

Karthikeyan Munirathinam and Dong-Weon Lee

**Abstract—** Harvesting triboelectric charges in the water without going through an electrostatic induction process could boost the output performance. Such designs successfully avoid using a dielectric layer and effectively transfer the triboelectric charges in the water. Herein, we report a volume-effect-based high-performance tubular nanogenerator (T-NG) for flowing water kinetic energy harvesting. The T-NG, with a friction layer-based electrode, makes direct contact with the flowing water and harvests triboelectric charges. The contact electrification process generates triboelectric charges in the water. Unlike triboelectric nanogenerators, the T-NG does not go through the electrostatic induction process and avoids dielectric layer thickness's influence on the output. A T-NG with a 30 cm length and 10mm diameter produces an output power of 5.5 mW at a load resistance of 10 M $\Omega$ . Since water has direct contact with the metal, the T-NG has been continuously placed in a water tub for four months to study its long-term stability. Further, the electricity produced by T-NG can be easily stored and used for building self-powered water monitoring systems.

## I. INTRODUCTION

The continuous growth of modern technologies and the Internet of Things (IoT) have witnessed an increasing global energy demand and put forward severe challenges to traditional power sources such as coal and oil. The draining and environmental destruction caused by these fossil fuels have led to continuous interest in renewable energy [1, 2]. Several renewable energy sources, such as solar, wind, and water, have been investigated to meet the global energy crisis. Specifically, water energy is a promising green energy source due to its abundance and rich forms on the earth. Besides, water energy exists in different forms, such as raindrops, river/ocean water, and flowing water. To date, various technologies (electromagnetic [3], electrostatic, [4], and electro-kinetic effects [5]) have been explored for harvesting water energy from the environment. Among them, electrostatic effect-based triboelectric nanogenerators (TENGs) are widely employed as promising techniques to harvest water energy from the environment.

The mechanism of triboelectric nanogenerators (TENGs) is contact electrification and electrostatic induction process [6]. Contact electrification and electrostatic induction occur between the dielectric layer and water (solid-liquid) interfaces. Hence, the number of triboelectric charges harvested from the water mainly depends on the dielectric layer used. The output current and power of the existing TENGs are less and need to be improved to drive the load

effectively. Few techniques have recently been reported to harvest triboelectric charges present in the water without going through electrostatic induction process [7, 8]. These nanogenerators produce high output voltage, output current, and high instantaneous power. Besides, the dielectric layer less energy harvesting technique needs more investigation for harvesting energy from the flowing water.

This paper reports a volume-effect-based tubular nanogenerator (T-NG) for flowing water energy harvesting. The T-NG mechanism is based on contact electrification between metal-liquid contact interfaces. Here, the dielectric material is avoided; the copper electrode directly contacts the flowing water and harvests triboelectric charges. A T-NG with 30 cm length and 10mm diameter produces an output power of 5.5 mW at a load resistance of 10 M $\Omega$ .

## II. METHODS AND MATERIALS

### A. Fabrication of Tubular Nanogenerator

The structure of the tubular nanogenerator was designed to effectively convert the triboelectric charges present in the flowing water into electricity. It has two layers, the inner layer is made of the electrode, and the outer layer is made of polymers. The inner electrode acts as the friction layer and current collector, while the outer polymer acts as a triboelectric charge inducer. The single electrode mode T-NG, with an electrode length and diameter of 10 cm and 1 cm, respectively, was rolled on a supporting tube. Next, the electrode layer of T-NG was covered with a polymer as an outer layer. After rolling the electrode and polymer layers, the T-NG was removed from the supporting tube. The ends of the T-NG were connected to the water inlet and outlet and sealed with waterproof tape. The conductive wires were used to connect the electrode and the external electrical circuits and measuring instruments.

### B. Working Mechanism

The single electrode-based tubular nanogenerator converts the triboelectric charges in the flow without going through the electrostatic induction. Here, the inner electrode act as a friction layer and a current collector, while the outer polymer layer induces the triboelectric charges. The mechanism of a T-NG can be described based on the volume of water entering and exiting the T-NG. Initially, the water flows from a household tap at a flow rate of 2.5 L min<sup>-1</sup>. The triboelectric charges were developed due to the

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contact electrification between water and the traveling pipe. When the positively charged initial water contacts the negative triboelectric polymer layer, it becomes negatively charged owing to solid-liquid contact electrification. Once the positively charged flowing water contacts the electrode, a positive potential difference is created between the electrode and the ground. The electrons flow from the ground to the electrode. Besides, the negative charge in the electrodes reaches a maximum when the water completely aligns with the electrode and produces a negative peak. As water flows forward, it leaves the electrode and produces a negative potential difference between the copper electrode and the ground, which allows electrons to flow from the electrode to the ground and produce a positive peak. Thus, the entry and exit of flowing water generate an AC output signal.

### III. RESULT AND DISCUSSIONS

To investigate the electrical performance of the tubular nanogenerator, the tap water was allowed to flow through the device at a steady flow rate of  $2.5 \text{ L min}^{-1}$ . The open circuit voltage and short circuit current of the tubular nanogenerator is shown in Fig. 1a and b. For a tube with a diameter of 10 mm, and an electrode length of 10 cm, the total voltage and current per cycle reached 136 V and  $8.6 \mu\text{A}$ , respectively. The output shows that the voltage increases with increasing load resistance, ranging from  $10 \text{ K}\Omega$  to  $100 \text{ M}\Omega$ , whereas the current and charge shows an opposite trend, as shown in Fig. 1c. The optimal power of the tubular nanogenerator remains insignificant below  $10 \text{ K}\Omega$  and reaches a maximum of  $250 \mu\text{W}$  at  $10 \text{ M}\Omega$  (Fig. 1d).

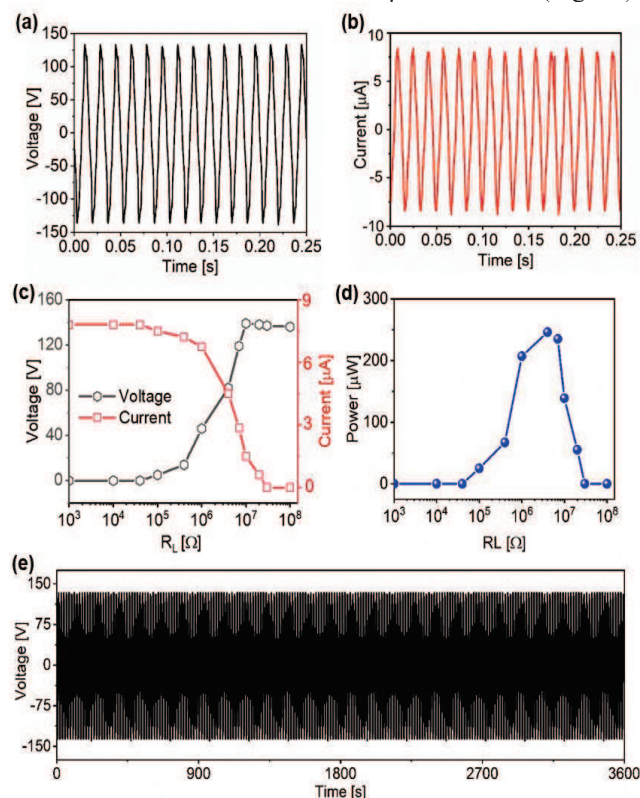


Figure 1. Electrical characteristics of the tubular nanogenerator with a diameter of 10 mm, length of 10 cm.

The long-term stability of the tubular nanogenerator shows that the voltage has no significant reduction after one hour of monitoring. This indicates the fabricated device's excellent mechanical robustness and working durability (Fig. 1e). Therefore, the adhesive electrode foil maintains strong durability with the water sliding even after continuous flow for long time.

### IV. CONCLUSION

In this paper, we reported a high-performance tubular nanogenerator (T-NG) for water energy harvesting. The T-NG, made of a copper electrode, has direct contact with the flowing water and harvests triboelectric charges. The T-NG goes through the electrostatic induction process and avoids the influence of dielectric layer thickness on the output. Hence, the T-NG exhibits a high output performance. Further, the electricity produced by T-NG can be easily stored and used for building self-powered water monitoring systems.

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