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Storage of energy harvested from a miniature turbine in a novel organic capacitor

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ABSTRACT

The potential of harvesting energy generated from a (5-cm) miniature wind turbine and storing the charge in a novel organic capacitor is experimentally investigated. The energy is generated by subjecting the wind turbine to different flow speeds between 2 and 8 m/s. A maximum output power of 0.2 W was attained with an optimum load resistance of 220 Ω at 8 m/s. The organic capacitor consists of layer-by-layer deposition of synthesized organic semi-conductive polymers, made of doping ionic liquid with non-conductive polymers, and metallic charge element made out of synthesized palladium (Pd) nanoparticles with a diameter of 6 nm. Scanning electron microscopy (SEM) images revealed uniformly distributed Pd nanoparticles over the entire substrate. Capacitance–voltage (*C*–*V*) measurements were carried out for the fabricated organic capacitor. The results exhibit large window gates that showed that the Pd nanoparticles are responsible for storing the electric charge. The performance of the organic storage device was evaluated through comparison with a commercial capacitor. The results show that the organic capacitor performed much better at lower frequency values. It was also observed the voltage produced at various airflow speeds was high enough to store the harvested energy in the organic capacitor.

1. Introduction

Interest in harvesting ambient energy to develop self-powered sensors has grown over the past two decades and is expected to continue particularly for the purpose of powering small sensors. Proposed energy harvesters include different concepts for harvesting vibration energy through piezoelectric or electromagnetic effects, solar energy through photovoltaic cells, and heat through thermoelectric effects [1]. Because kinetic energy of air and water is large, there has also been interest in harvesting fluid flow power. Although advances are being made for harvesting air power through piezoelectric transduction [2], the efficiency of harvesting this power through turbines and electromagnetic generators remains higher [3].

Centimeter-scale micro wind turbines (CSMWT) have been proposed to harvest small levels of energy [1,3–5]. The harvested energy can be used to power small devices or could be integrated in the development of self-powered sensors and actuators that can be used to setup wireless network systems and monitoring systems for different purposes. Rancourt et al. reported the capability to generate 130 mW with a power density of 9.38 mW/cm^2 from a 4.2 cm micro-wind turbine at a wind speed of 11.8 m/s. Although high in power generation, the availability of such high wind speeds remains a major concern for practical implementation. They also asserted that at low wind speeds, the friction in the generator and electric resistance reduced the energy conversion and the maximum overall efficiency was only 1.85%. Other investigators considered different types of wind turbines and blade rotors. Still, the power levels of these CSMWT show the need for combining them with compact, reliable and highly efficient energy storage devices.

Combining miniature energy storage devices with small size energy harvesters is of particular interest in the development of usable energy harvesting systems that can be used to power small electronic devices, sensors or actuators. Storage devices are effective in overcoming the limitations of the small power levels and fluctuations of energy harvesters. They would help in ensuring continuous operation of self-powered systems and devices. Park et al. [6] investigated the feasibility of integrating a lithium-polymer rechargeable battery with a centimeter scale micro wind turbine to power a wireless sensor on a cable-stayed bridge. They

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showed that the micro-wind turbine installed under the deck of the bridge successfully charged the battery. Though lithium ion batteries can be used to store energy, there remain few issues including environmental contamination and potential for fires and explosions [7].

Organic capacitors do not have the above adverse effects. The blended semi-conductive polymers used in manufacturing the organic capacitors do not require a clean room, thus making them cost effective and easy to manufacture. Al-Haik et al. [8] and Ayesh et al. [9] examined the use of different types of nanoparticles to be used as storage elements in the fabrication of a storage device. They developed novel conductive polymer blends that act as the semiconducting layers and were able to store energy in nanoparticles placed between these layers. In this work, we experimentally investigate the integration of a centimeter-scale wind turbine energy generator with an organic capacitor as a combined energy harvesting/storage system. Specifically, our objective is to determine specific response characteristics of the combined system through its comparison with a system that integrates the wind turbine with a commercial capacitor. A 5 cm four bladed fan type rotor that yielded high power levels over a wide range of wind speeds is used as the energy harvester. Conventional spin coating, vacuum-evaporating films and layer-by-layer sequential deposition/adsorption films were used in the fabrication of the organic capacitor.

2. Experimental setup

2.1. Energy harvesting from CSMWT

The centimeter-scale wind turbine was placed in the test section of an open circuit wind tunnel of the suction type. The experiments were performed over a speed range between 2 and 8 m/s $\pm$ 0.5% uncertainty. A Pitot tube with a differential pressure gradient was used to measure the air speed in the test section. The angular velocity of the wind turbine was measured by a non-contact laser type digital tachometer. The output AC voltage generated by the wind turbine was measured using a USB 6009 National Instruments data acquisition card. The sampling rate was set at 2000 Hz and recorded over periods of three seconds. Fig. 1 shows an illustration of the experimental setup. The wind turbine connected to the circuit diagram where the capacitors are allowed to store the generated charge.

External load resistors with resistances varying between 10 Ω and 1 kΩ were connected in series with the wind turbine to study the performance of the micro-generator. Fig. 2 shows the variation of the output peak voltage and harvested power with the load resistance for different flow speeds. Clearly, the output voltage increases as the air speed is increased. The voltage measurements also show that it increases with the load resistance up to a value of about 220 Ω. Beyond that value, the output voltage remains more or less constant. As for the output power the results show that the largest harvested power is obtained when load resistance is 220 Ω for all flow speeds. At the airflow speed of 8 m/s, the maximum harvested power is about 191 mW, which corresponds to a power density of about 9.72 mW/cm^2.

2.2. Organic capacitor–energy storage device

A typical metal-insulator-semiconductor (MIS) capacitor consists of a semi-conductive layer, insulating layer and charging layer sandwiched between two metal electrodes. We are proposing a new type of capacitor that combines novel conductive polymers and nanoparticles. For synthesizing the semiconducting polymer blend, two non-conductive polymers, namely, poly vinyl alcohol (PVA) and poly-acrylamide-*co*-acrylic acid (PAA) with average molecular weights of 61,000 g/mol and 5,000,000 g/mol, respectively, were used. Five grams of each crystal state polymer was dissolved separately in 100 mL of deionized water. Both solutions were set at 90 °C and underwent vigorous mixture using a

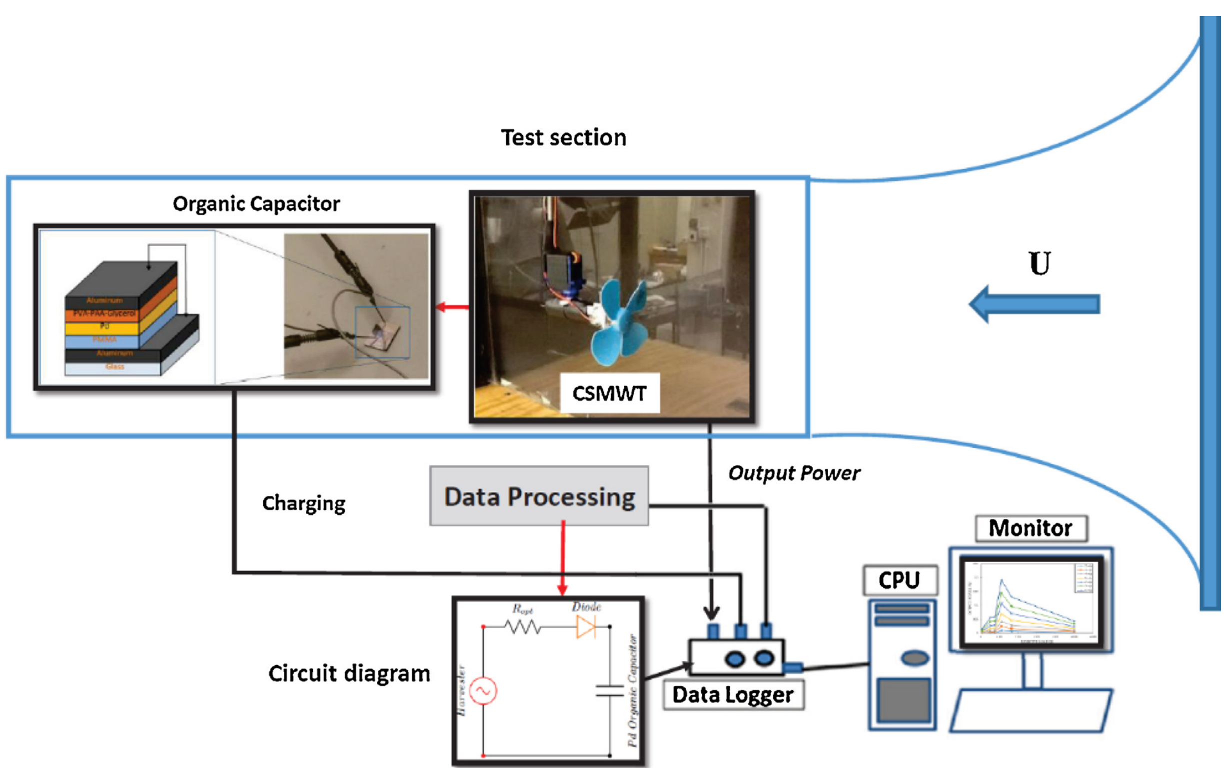

Fig. 1. Schematic of the experimental setup.