Nano Energy (2015) **16**, 329–338

Available online at www.sciencedirect.com

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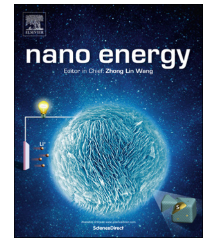

COMMUNICATION

Multi-unit hydroelectric generator based on contact electrification and its service behavior

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Received 8 June 2015; received in revised form 6 July 2015; accepted 7 July 2015
Available online 18 July 2015

KEYWORDS
Hydroelectric generator;
Multi-unit;
Enhanced efficiency;
Water energy harvesting;
Resource recycling;
Service behavior

Abstract
Water is one of the most abundant energy sources in our environment and hydroelectric power has been one of the main forms of macro-energy supply. However, for harvesting green micro-energy from water presented in our residential zone, industry or agricultural irrigation, traditional electromagnetic hydraulic turbine generator has limited applications due to its large size, complexity and high cost. Here we report a novel design of the multi-unit hydroelectric generator (HEG) for harvesting water-related energy based on contact electrification. The instantaneous output power density of the multi-unit HEG array is 0.07 W/m^2, which is 9 times of that from the individual HEG with the same dimension. Moreover, the rational design of the multi-unit HEG can increase the safety for its future service. By integrating with the multi-unit HEG, the household faucet can be a power source to supply clean energy continuously. Given the compelling features, such as, highly efficient, easily implemented, lightweight and extremely cost-effective, the multi-unit HEG renders a promising approach toward clean energy harvesting from ambient environment.

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http://dx.doi.org/10.1016/j.nanoen.2015.07.004
2211-2855/

Introduction

As a response to the increasing threat of energy crisis and environment pollution, harvesting energy from ambient environment has attracted interests for searching renewable and low-carbon emission energy sources to relieve our sole reliance on finite fossil fuels [1,2]. Different sources in the environment including heat [3], wind [4,5] and water [6–8] are the potential options for meeting the growing energy consumptions, realizing the self-powered sensor systems [9–15] and have captured the worldwide attention. Among these candidates, water presenting in the form of ocean waves and tides and river flows contains huge amounts of energy, which is inexhaustible and has much less dependence on daytime, climate and weather.

From the built of the first hydropower station in France in 1878, hydroelectric power [16–18] harvesting the potential energy of water has been one of the main forms of energy supply for the development of modern society due to the advantages that it possessed, such as low cost, high efficiency, easy to regulate, does not consume fuel in the operation, good sustainability. Besides, the electricity generation process has no excretion of harmful substances, which makes the hydroelectric power a kind of green energy. Generally speaking, falling water is channeled through a turbine that can convert the potential energy of water into mechanical power. Hydroelectric power plants capture the mechanical energy released by water falling through a vertical distance and then transform this energy into electricity. The electricity generated from the potential energy of water is obtained by the rotation of the water turbines driven by water motions. The outputs of the electromagnetic generator can be regulated by adjusting the water flow or water level difference. On the other hand, most previously demonstrated converters for harvesting energy from water motions are based on electromagnetic generators [19–22], which are bulky, complicated and costly. The limits that not all the forms of water are suitable for driving a turbine confine the application of harvesting water-related energy in our living environment for the electromagnetic generators. Therefore, a lightweight, cost-effective and easily implemented device is desirable to harvest water-related energy in our environment for powering other sensing systems or electronic instruments.

In this work, we demonstrated a novel design of a multi-unit hydroelectric generator (HEG) for harvesting water-related energy in our living environment. Based on contact electrification, which is a universal phenomenon but always regarded as an undesirable effect due to its potential hazard to electronic systems and public safety, the multi-unit HEG can transform the water energy into electricity. The rational structure design can effectively enhance the efficiency of the multi-unit HEG compared with individual HEG for harvesting water energy. Besides, the multi-unit HEG is beneficial for the future practical application of the HEG, because the damage of a unit will not bring about the completely failure of the multi-unit HEG. With the flowing rate of the tap water of 35 ml/s, the instantaneous output power density of the multi-unit HEG array is 0.07 W/m^2, which is far greater than that of the individual HEG with the same dimension. The clean energy harvested by the multi-unit HEG can be utilized to instantaneously drive light emitting diodes and charge commercial capacitors. The output of the multi-unit HEG can be further improved by vertically integrating more working units. Given the simple structure, extremely low cost, the multi-unit HEG renders a green alternative to traditional methods for blue energy harvesting.

Methods

Multi-unit HEG fabrication

The fabrication of the multi-unit HEG was started with the preparation of the electrode arrays. An acrylic sheet (3.5 cm*6.5 cm) was served as the substrate. Take the eight units multi-unit HEG as an example, the Al foil (3 cm*6 cm) was cut into eight pieces in the same size and attached them on the prepared substrate. Subsequently, a rectangular (6 cm*8 cm) PTFE (Polytetrafluor-oethylene) film with a thickness of 50 μm was washed with acetone, isopropyl, and alcohol, consecutively. The patterned microstructures on the surface of the PTFE film were obtained by applied the Steel–Wire Screen to the film with pressure of 15 Mpa for 10 min. Then it was immersed in alcohol for two hours to eliminate its surface charges. After that, the PTFE film was adhered onto the electrode array. The fabrication process of all the HEG mentioned in the article was like those above. The multi-unit HEG for regulating the output was obtained by replacing the acrylic substrate with kapton film with thickness of 200 μm and bent it into a curved shape. Finally, the conducting copper wires were connected to the electrodes as leads for subsequent measurement.

Characterization

The flowing water from a household faucet was applied to the multi-unit HEG for electric output measurement. The multi-unit HEG was attached onto an inclined acrylic sheet during the test. A digital oscilloscope (DS4052, RIGOL) was used to measure the electric outputs of the multi-unit HEG.

Results

The structure diagram of the fabricated multi-unit HEG is shown in Figure 1a, which is composed of an acrylic substrate, Al electrode array and PTFE film. Parallel strip-shaped electrodes with a fixed gap in between act as the electrode of every unit in the multi-unit HEG. The PTFE film was chosen as the contact material for its hydrophobic and high negativity in the triboelectric series and surface modification on the PTFE film was employed to intentionally create patterned surface roughness at the microscale. The microstructures were obtained by applied the Steel–Wire Screen to the PTFE film with controlled pressure. Figure 1b displays the scanning electron microscopy image of the PTFE film. Regular netted microstructures are distributed on the surface of the PTFE film. This approach can be utilized to fabricate large-sized PTFE film with a uniform microstructure. An acrylic substrate was selected due to its good machinability, lightweight and flat surface.