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Full Length Article

Design and implementation of a new contactless triple piezoelectrics wind energy harvester

Erol Kurt [a], Francesco Cottone [b], Yunus Uzun [c,*], Francesco Orfei [b], Maurizio Mattarelli [b], Davut Özhan [d]

[a] Department of Electrical and Electronics Engineering, Gazi University, TR-06500, Teknikokullar, Ankara, Turkey
[b] Department of Physics and Geology, University of Perugia, 06123, Perugia, Italy
[c] Department of Electrical and Electronics Engineering, Aksaray University, Aksaray, Turkey
[d] Mardin Vocational School, Artuklu University, Mardin, Turkey

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ABSTRACT

The features of the new designed and constructed harvester are examined. The harvested power of three piezoelectric layers having different masses (i.e. different natural frequencies) has been explored. These layers have the same length around the harvester body, whereas a permanent magnet (PM) attached to the shaft rotates by low speed wind and this PM repels these three piezoelectric layers with a 120° phase shift. Since PM and the PMs located to the tip of the layers do not contact, this system improves the lifetime of the harvester. The measured harvested power in the low wind speeds (i.e. 1.75 m/s) is of the order of 0.2 μW. The waveform includes many subharmonic and superharmonic components, hence the total harmonic distortion (THD) is found around 130%, which is fairly high due to nonlinear effects. Although the system shows an high THD, the 20% of the signal can be rectified and stored in the capacitor for the use of harvested energy. A scenario has also been created for a resistive load of $R_L = 1$ MΩ and 100 kΩ for various wind speeds and it has been proven that the harvester can feed the load at even lower wind speeds. In addition, extra power beyond the usage of the load can be stored into the capacitor. The proposed harvester and its rectifying unit can be a good solution for the energy conversion procedures of low-power required machines.

Introduction

There exist growing works on the long-life energy required devices such as unmanned aerial vehicles, sensor nodes, pacemakers, etc [1–3]. After the recent improvements in nanotechnology, many piezoelectric materials and related structures can be fabricated from micro to macro-scales in various geometries upon the application needed [4,5]. In that frame, macrostructures or devices such as bicycles, shoes, arm and leg connected piezo-powered systems have also been frequently studied in addition to micro structures [6–9].

* Corresponding author. Fax: +90 312 2028550.
E-mail address: yunusuzun38@hotmail.com (Y. Uzun).

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Nowadays, the literature has many harvester applications [10]. As the main goal to generate energy, leaf type piezoelectric generators [11], contacted windmills [12,13], two degrees of freedom beam type wind generators [14] and flow induced self excited wind power generators [15] can be mentioned. Many of them are operated with mechanically contacting piezoelectric layers [16].

As the most compact harvester tool, piezoelectric materials are widely used for the wireless devices in nature, industry and human activities [17–20]. It is mainly due to their easy installation and maintenance, compact structure and high energy density [21]. According to last technological achievements, it has become much cheaper relative to the past years. For that reason, piezoelectric components start to find good place among the other energy conversion systems such as solar panels, thermoelectric generators, etc.

By considering the low energy requirements, the piezoelectric generators give a power scale of μW or mW, which are already sufficient for many engineering applications. On the one hand, most of the electrical devices use batteries and that creates the maintenance problems because of the either the environmental issues or their complex recycling processes. Besides, the lifetime of a battery is too limited and this lifetime can be increased further by different external and environmental-friendly resources [22,23]. In that context, an additional piezoelectric harvester can be mounted to charge the batteries in real time or feed the device itself, continuously.

The harvesters are such devices that can convert ambient vibrations into a useful electrical energy. The main research activity aiming at improving the harvesting performance is into three main groups: the production of piezoelectric materials, the design of mechanical systems and the implementation of efficient conversion circuit. Although the harvested energy per material volume of a piezoelectric is higher than any conventional solar and wind energy applications, piezo-systems have some issues and should be further improved for better energy solutions. For instance, the wind speeds of our interest are in the range of 1.6 m/s–3.2 m/s due to the fact that the generated force from small blades (around 1.3×10^{-3}–3.2×10^{-3} m^2) is too small around 0.1 N at those speeds. That condition makes the use of any type of electromagnetic harvester or conventional turbines be impossible, thereby the piezoelectric-based devices have certain advantages for the feeding of small-scale devices in that manner. However, the other task should be the solution to the artifacts stated above by designing those.

The main objective of the present study is to show the useful electrical power generation from the present complicated voltage waveforms and characterize the output power with a resistive load for various wind speeds. In addition, this new harvester with triple piezoelectric layers is introduced for a micro-range power generation without any mechanical contact. Therefore it has certain advantages to increase the mechanical durability of the system and piezoelectrics as well. The proposed harvester can be used in low power applications being far away from any electrical grid and it can be fed at low wind speeds and an extension to the life-span of the battery can be enabled. Besides, the energy range can be increased further by using thicker piezoelectric layers in the same harvester.

The paper is organized as follows: Section The experimental setup of the harvester gives some introductory information on the design and construction of new harvester and the preliminary tests. Section Theoretical background provides a brief explanation of the theory as the preparation to the time-dependent simulations. Experimental results carried out in wind tunnel along with power consumption features of the weather station are presented in Section Results and Discussion. Finally, the concluding remarks are given in the Conclusions Section.

The experimental setup of the harvester

The wind energy harvester consists of four main parts (see in Fig. 1(a)): A propeller which can rotate freely by the wind, a shaft transferring the mechanical rotation to the magnet, a piezoelectric unit including three layers and the electronic part, which is responsible to regulate and store the harvested electrical signal from the terminals of the piezoelectric layers.

The three layer structure of the harvester occurs due to three separate piezoelectric layers, which are located with 120° angle to each other on a circular geometry. Each layer tip having a small permanent magnet is oriented in such a way that the magnet on the shaft can repel it when it comes to the opposite. Although the device has three identical piezoelectric layers, the magnet numbers at the tip of them differs. Indeed, that affects the natural frequency of the layers due to the increase at the magnet mass. The higher mass creates lower frequency due to the buckling formation along the gravity. Note that in order to provide the security of the layers, a cylindrical polyethylene material has been fixed on the shaft. It prevents the damage of the piezoelectric layers especially at high wind speeds, since the nonlinear effects can attract the layers into the shaft and that lead to damages on the layer. When the wind flows through the blades as in the wind tunnel tests (see in Fig. 1(b)), the shaft rotates about the shaft axis and the permanent magnet attached to the middle of the shaft just inside the polyethylene material is rotated. A more detailed form of the setup is presented in Fig. 1(c and d) in order to determine the units of harvester and its operational parts. The blades are directly connected to the central shaft, which as responsible to transfer the rotational movement to the permanent magnet housed in the polyethylene cylinder at the right side (Fig. 1(d)). Note that the cylinder has certain lateral regions in order to stop the tip of the layers, thereby prevent them to be damaged. As shown in Fig. 1(c), the body part of the harvester includes all the piezoelectrics, which are responsible to generate electricity from the mechanical oscillations. When the magnet gets closer to each layer tip, the layer has been bent without any mechanic contact, since the poles of the magnets have been adjusted same. Every wind speed creates a vibration and that is then transferred into the electrical potential on the layers.

This wind energy harvester has a novel structure due to its contactless operation to the shaft. According to the literature, we have another contactless harvester study, however it is a single layer device and has much harmonics [24]. Indeed, the optimal power generation is an important task for such systems, which has high harmonic waveforms. Within that

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