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Power control optimization of a new contactless piezoelectric harvester

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ABSTRACT

In this study, we propose an optimization scheme for the control of a piezoelectric wind energy harvester. The harvester is constructed by a blade in front and a magnet in the rear in order to sustain a magnetic repulsion by another magnet located on the stable harvester body in a contactless manner. For such a new harvester, the control scheme is missing in the literature in the sense that the harvester is new and an overall optimization study is required for such a device. In that context, the optimization has been realized by using a new current control law based on the harvester piezoelectric terminal voltage and the layer bending. The proposed control law can impose a second order linear dynamics although the magnetic effects can yield to nonlinear magnetic force relation. In order to improve the new control strategy, a Particle Swarm Optimization algorithm (PSO) has been applied, since there is a nonlinear dependency among the control parameters, the collected energy and the bending force mean values. According to results, the captured electrical power has a high increasing trend with respect to the only-voltage-based (OVB) control as the current study proves. On the contrary, the artifact of the method is that the obtained power is too low to increase the mean bending forces and it requires much complicated control system.

Introduction

In order to supply the increased demand of energy caused by the population growth and greater power consumption, invention of new energy harvester systems and their optimization have become key points for a few decades. Indeed, when the issue is to construct optimized energy harvester systems, the balance between demand and supply is also vital problem to deal from a multidisciplinary view. It is desirable to obtain sustainable, safe and world-wide applicable methods [1–3]. Before 2000's, the most of energy supply was based on fossil fuels working in so-called conventional energy systems. However, both the limitations in the supply and the globally inhomogeneous distribution make the usage of those fuels inefficient.

The combination of solar and wind energy systems has become an alternative research and practice area [4]. Similarly, a study made by Ref. [5] proposed an energy generation model that includes factors such as emissions reduction, minimization of imported energy and social acceptance.

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In the frame of low power systems, a significant increase has been experimented; indeed energy harvesting systems in that power scale allows energy supplies for low power electronic equipment such as wireless sensors, pacemakers and health monitoring systems. In the last decades, these low power systems have been invented or improved to be operated even without any battery. In addition, harvesters have served as an auxiliary power device, which enhances the life time of the batteries with suitable maximal power point tracking mechanisms [6–9].

In principle, all harvester systems are designed to obtain electrical power from ambient and they transform it into a utilizable form of energy for low power devices. Several energy harvesting methods such as vibration, solar, thermal gradient, etc. have been developed during the last years [6,10,11]. There are many ambient vibrations such as human and machine motions, wind or seismic actions in the environment.

Energy harvesting could be a feasible alternative for micro powering with the main advantage of no need to replace batteries. Power sources could be find in photons (light, infrared, radio frequencies), kinetics schemes (vibrations, human motion, wind power, hydropower) and thermal systems using the temperature gradients [12]. The most important benefits of energy harvesting are based on long lasting operability, cost effective, usually free of maintenance and no need of charging points. Additionally, these systems are very useful in applications for hard natural conditions.

Vibrations can be converted into energy by several techniques: electromagnetic, electrostatic/capacitive and piezoelectric [13]. Among the aforementioned techniques, piezoelectric have some advantages: high power density and voltage. Furthermore, the piezoelectrics are suitable to be optimized for a certain excitation frequencies and that can help to increase the system efficiency drastically [14,15]. The materials used for piezoelectric conversion are naturally-occurring ones as crystals (Quartz, Rochelle salt), ceramics and polymers [16–18].

The main objective of the paper is to show how a novel optimization system has been used in order to increase the captured energy by energy harvesting. Due to this objective, a new piezoelectric control law has been designed using swarm optimization algorithms. In the literature, there are a number of control algorithms which try to increase the captured power like [19]. In our study, we have introduced the voltage and the deflection of piezoelectric beam which highly enhances the mean power captured by the energy harvester.

The paper is structured as follows: the second section presents the main objectives and the general schema of the wind energy harvester. In the third section the energy harvester model has been explained and the proposed control law in this analyzed. The fourth section is devoted to design the optimization algorithm, describing the general steps and the cost function, while the obtained results are discussed in the fifth section. Finally, the last section gives our main conclusions.

The wind energy harvester

The energy harvester used in this work has been developed by the Alternative Energy Researches Group of Gazi University and some preliminary findings and features of the device have been reported in previous papers [20,21]. This system shown in Fig. 1 has a wind turbine that collects the energy from the wind and induces a bending deflection by the help of two permanent magnets (one in the rotor side and other in the piezoelectric beam).

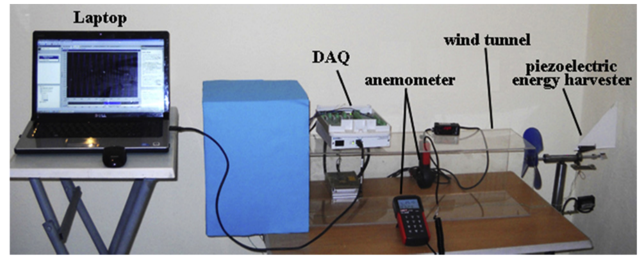

Fig. 1 – The harvester and the wind tunnel test setup.

The tests of the system can be easily realized by using a small wind tunnel, an anemometer, the harvester, a data acquisition card (DAQ) and a laptop. The system enables us to record the data (i.e., harvested voltage, deflection, velocity and acceleration) with high precision.

This set of permanent magnets let us to build a contactless energy transfer between the wind turbine axis and the piezoelectric system, eliminating the physical damages due to any contact with a shaft. In this work, the control law has been proposed in order to improve the bending and the collected power. The control law has mainly two inputs: the piezoelectric terminal voltage and the bending deflection.

In comparison with previous works [21], the control law can completely impose the second order dynamics. Therefore, the control law parameters have been optimized by a Particle Swarm Optimization (PSO) algorithm, because there is a nonlinear dependency between the control law parameters and the cost function. The cost function takes into account the mean power harvested and the mean bending force obtained in different wind turbine regimes.

Problem statement

The main problem to solve in this paper is to increase the mean power captured by changing the control law and to optimize the control parameters by using a Particle Swarm Optimization algorithm (PSO). Within that frame, initially the block diagram of the present work is presented in Fig. 2.

Here, the inputs and outputs are defined in Tables 1 and 2. The main problem is to choose an appropriate cost function, since it should be strongly linked to the objective that is pursued. In this case, the objective is to increase the power captured by the harvester as the first step. In addition to that energy increasing objective, we should keep the bending force less enough. That is also important to prevent the piezoelectric layer from any damage.

In the optimization cost function, we have proposed a proportionally inverse value to the mean captured power. The mean bending force have been applied as the inequality restriction. If a certain upper bound is found, the cost function is highly increased; otherwise the cost function is proportionally decreased by considering the mean captured power. The