



# Improving power output of inertial energy harvesters by employing principal component analysis of input acceleration



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## ABSTRACT

In this paper we propose the use of principal component analysis to process the measured acceleration data in order to determine the direction of acceleration with the highest variance on given frequency of interest. This method can be used for improving the power generated by inertial energy harvesters. Their power output is highly dependent on the excitation acceleration magnitude and frequency, but the axes of acceleration measurements might not always be perfectly aligned with the directions of movement, and therefore the generated power output might be severely underestimated in simulations, possibly leading to false conclusions about the feasibility of using the inertial energy harvester for the examined application.

## 1. Introduction

Energy harvesting as a mean of obtaining useful electrical energy from ambient energy of surrounding environment has become a mature research field with well characterized principles. Sources of harvestable energy and devices for its conversion to electric energy vary depending on the application. Possible options might include one or more of following sources and transduction methods [1]: solar energy, transduced through photovoltaic cells; thermal gradient, convertible utilizing TEG generators; RF electromagnetic waves, exploitable using antennas, or kinetic energy, which can be converted with electromechanical energy harvesters.

Basic classification of electromechanical energy harvesters can be done by assigning them into two groups according to the operation principle: direct force harvesters and inertial harvesters [2]. While direct force devices exploit the direct application of the loading force to the transducer and the dynamics of such a system is mostly dominated by the loading force, inertial harvesters utilize the kinematic excitation of the frame to achieve a relative oscillatory movement between the proof mass and the frame of the harvester.

Another way of classification is based on the transduction physical principle. Commonly employed conversion methods include Faraday's induction law [3–5], piezoelectric effect [6–10], electrostatic effect [11,12], magnetostriction [13,14], and newly also triboelectric effect [15,16].

This paper is focused on a method for potential improvement of the power output of inertial energy harvesters by locating and exploiting principal directions of acceleration with given frequency in a measured dataset.

## 2. Inertial energy harvesters

Inertial harvesters can be understood as accumulators of mechanical energy, which is being stored in the system in as kinetic

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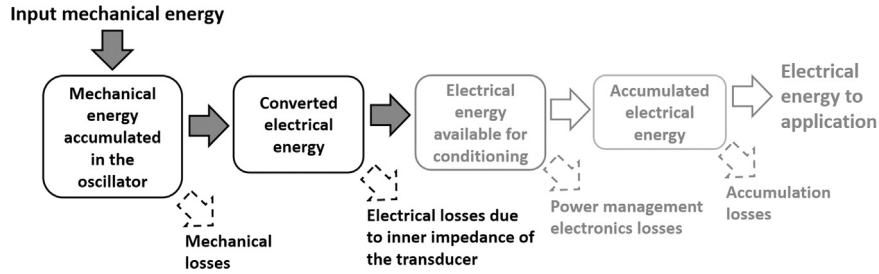


Fig. 1. Energy flow in the energy harvesting system.

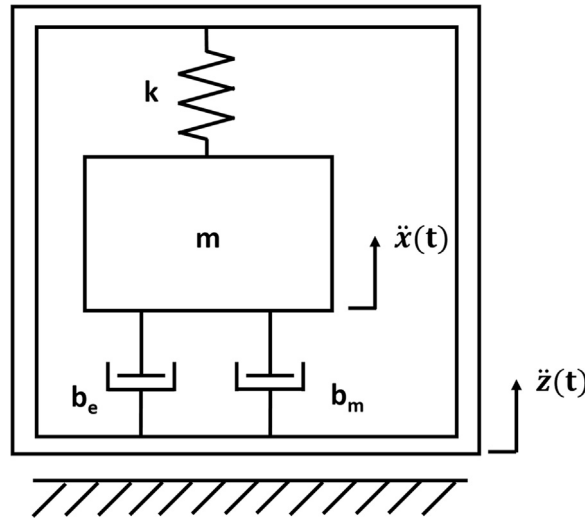


Fig. 2. Model of 1dof inertial energy harvester.

energy of the proof mass and potential energy in the spring element. During the operation a part of the accumulated mechanical energy is being extracted and converted into electrical energy by one of the transducing principles, using either electrodynamic or electrostatic damping force. Some part of the energy is inevitably lost due to the mechanical losses (Fig. 1).

Let us assume that given 1 degree of freedom (dof) inertial harvester consisting of proof mass  $m$  with electrodynamic damping characteristics given by combination of mechanical and electrical damping  $b_m$  and  $b_e$ , respectively, contains linear stiffness  $k$  and is excited by vibrations of the frame  $\ddot{z}$  (Fig. 2).

Its dynamics is described by the well-known motion equation

$$\ddot{x} + \frac{[b_e + b_m]}{m} \dot{x} + \frac{k}{m} x = -\ddot{z} \quad (1)$$

where  $x$  represents the displacement of the proof mass. Natural frequency of such a system is found as  $\Omega = \sqrt{\frac{k}{m}}$  and its damping ratio as

$$b_p = \frac{b_e + b_m}{2m\Omega} \quad (2)$$

The quality factor of the harvester is given by

$$Q = \frac{1}{2b_p} = \frac{m\Omega}{b_e + b_m} \quad (3)$$

Motion Eq. (1) can then be rewritten as

$$\ddot{x} + \frac{\Omega}{Q} \dot{x} + \Omega^2 x = -\ddot{z} \quad (4)$$

In case of harmonic excitation  $\ddot{z} = A_v \cos(\omega t)$  the power output of the linear energy harvester is proportionally dependent on the

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