

THE HYBRID VIBRATION GENERATOR, A NEW APPROACH FOR A HIGH EFFICIENCY ENERGY SCAVENGER

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Abstract: This paper presents a new approach for optimizing the power transfer from vibration driven energy scavengers to a storage element. A hybrid generator consisting of the combination of a one-sided clamped swinging bimorph as main generator and a stationary inductive coil as trigger generator is shown. The signal from the coil is used to trigger a SSHI-interface to enhance the power transfer. The results of parameter studies for an optimal generator design as well as simulation and first measuring results obtained with a hybrid generator testing device are presented and discussed in the presented paper.

Keywords: energy harvesting, power transfer optimization, vibration

INTRODUCTION

Applications demanding an energy scavenging micro-generator enlarge more and more. Certainly one reason is the possibility of a long term, battery free and wireless operation. However, the power delivered by those generators is commonly non-continuous, fluctuant and low in their voltage amplitude. In contrast most of the applications consist on periodic operation sequences with corresponding power supply requirements. Therefore, because of the asynchronous nature of the generator an energy buffer is needed, which compensates the energy requirement between the actual generator output and the energy consumption of the application [1]. In order to harvest continuously the maximum possible energy, a permanent load adaptation of the generator as well as an efficient rectification, voltage conversion and energy storage is required [2].

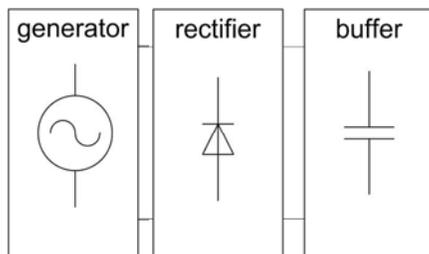


Fig. 1: Energy scavenging device, consisting of the signal generator, the signal conditioner and the storage element.

To maximise the available energy, it is important to optimize the mechanical properties of the scavenger as well as the energy transfer from the scavenger to the storage element. A big amount of the produced

energy gets lost on its way from the scavenger to the storage cell.

A schematic of a standard scavenger device is outlined in Fig.1. It consists of the three main components: the signal generator (mostly on piezoelectrical or electroinductive base), the storage element (capacitor or accumulator) and the signal conditioner between both.

Due to the fact, that the generator energy is transferred not till then the generator voltage exceeds the actual DC-voltage level of the storage, a more or less part of the energy delivered by the generator remains unused. This effect can be seen in Fig. 2.

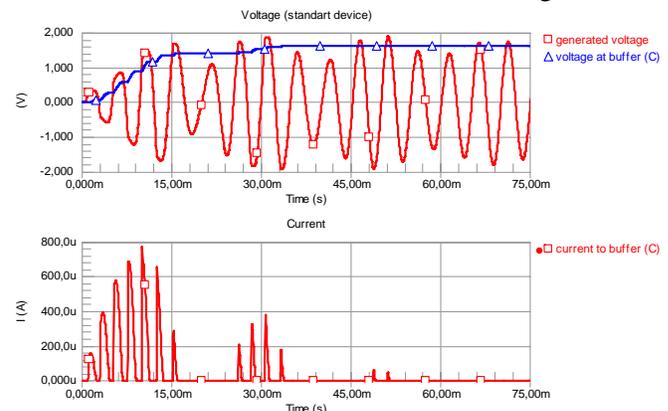


Fig. 2a) Typical voltage waveforms produced by a vibration energy scavenger and the voltage level at a storage element (capacitor). Fig. 2b) shows the current flow from the generator to the storage element. Energy can only be stored if the generated voltage exceeds the actual voltage at the storage element.

This results in a very low efficiency and a tremendous

extension of the recharge time. This effect can be interpreted as a mismatch between generator source resistance and storage internal resistance. The last one is strongly varying along the storage process.

THEORY / SIMULATION

To overcome the awkward situation the SSHI/SSHC technology described by Guyomar et al. [3] can be used. For the SSHI/SSHC technology an additional circuit with a control unit is added to the standard energy scavenging device. The SSHI interface is placed between the generator and the rectifier unit as shown in Fig. 3.

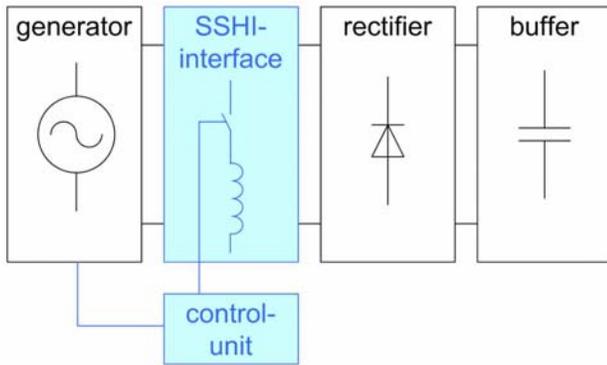


Fig. 3: Energy scavenging device. For the SSHI/SSHC device an additional circuit with control unit is needed.

The basic concept of the SSHI technology [4] is to switch-on momentarily a coil in parallel to the piezoelectrical generator or a capacitor in series to the inductive generator as shown in Fig. 4.

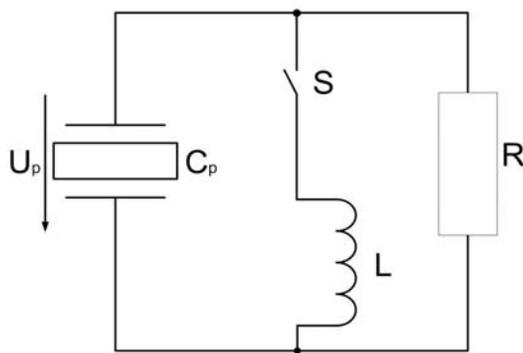


Fig. 4: Simplified model of a SSHI circuit, consisting of piezoelectric scavenger, switch, inductor and load resistor.

To simulate the effect of the SSHI technology an equivalent circuit shown in Fig. 5 is used [5]. It consists of an AC voltage source, a resistor, an inductor, a capacitor in series and a capacitor in parallel.

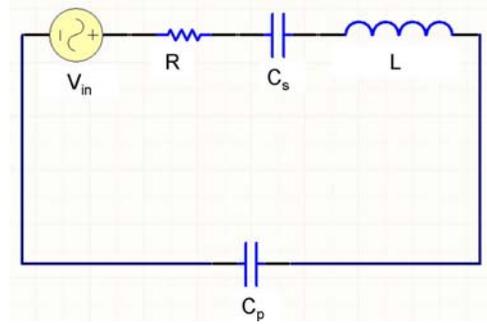


Fig. 5: Equivalent circuit of a piezoelectric energy scavenger with its clamped capacitor and equivalents for the mechanical components: vibration source (voltage source), the moving mass (inductor), the spring constant (series capacitor) and the mechanical damping (resistor).

The admittance of this circuit can be calculated as:

$$Y = \frac{1 - \omega \cdot C_p \cdot \left(\omega \cdot L - \frac{1}{\omega \cdot C_s} \right) + j \cdot \omega \cdot C_p \cdot R}{R + j \cdot \left(\omega \cdot L - \frac{1}{\omega \cdot C_s} \right)} \quad (1)$$

By measuring the impedance characteristics of the piezoelectric bimorph with a network analyzer, it is possible to calculate the values of the passive components. The frequency and the acceleration of the vibration source define the parameters of the AC voltage source.

This equivalent circuit is used to simulate the behavior of the generator and the SSHI/SSHC circuits with SPICE simultaneously.

The efficiency benefit obtained with SSHI is shown in Fig. 6. This favorable result is obtained under the assumption that the switching points are well defined.

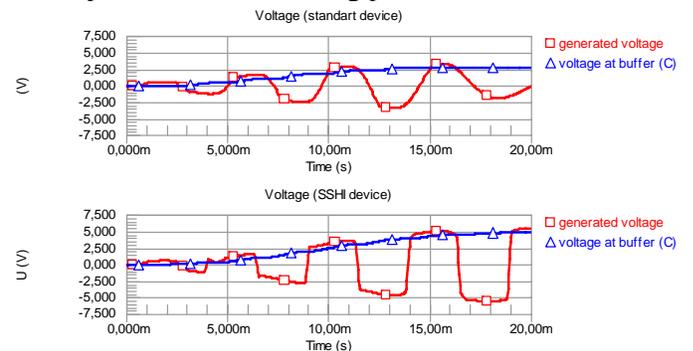


Fig. 6: Simulation results for a standard scavenging device (a) and a SSHI device (b) at same excitation. The storage voltage with SSHI rises 2 times faster than without SSHI.

But, in practice it is rather difficult if not impossible

to realize that with the needed accuracy. Especially under varying excitation conditions an unknown phase deviation takes place in the system which cannot be eliminated in a reproducible manner. Unfortunately, the phase drift is a highly sensitive influencing parameter. This can be seen in Fig. 7.

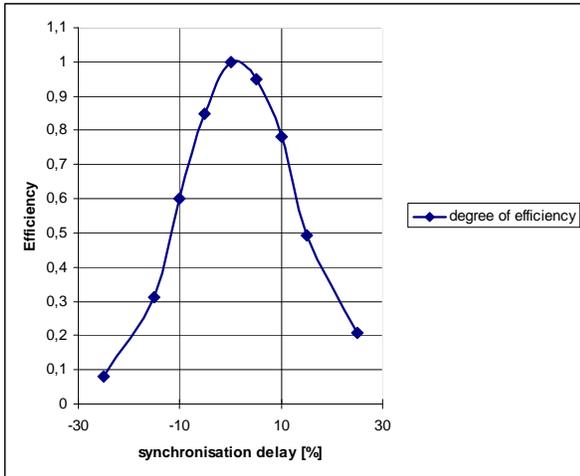


Fig. 7: Simulation of the SSHI-efficiency dependent on the deviation of the optimal switching point.

Fig. 8 shows the energy transfer at optimal switching conditions and with a time displacement of the switching point of 10% of the period of the excitation frequency. After 250ms the energy transfer of the system with optimal switching point is nearly twice as much as the one of the system with 10% time displacement.

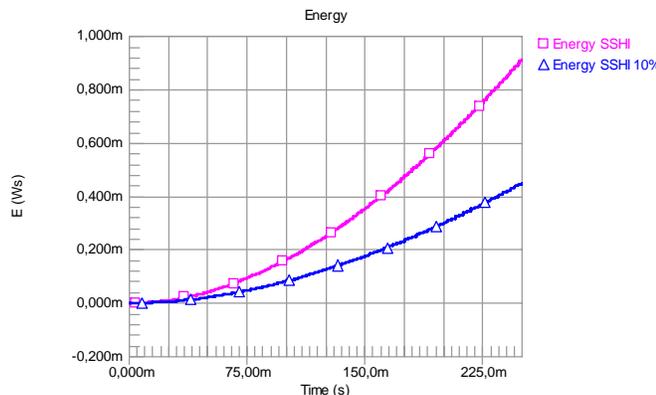


Fig. 8: Energy transfer at optimal switching conditions and with a time displacement of the switching point of 10% of the period of the excitation frequency.

This problem can be solved by introducing beside the main generator, which produces the storage energy as before, a second generator whose task is to yield exact trigger points for the SSHI/SSHC circuitry. The so

called trigger generator remains totally unloaded and is exposed to the same excitation as the main generator. The ensemble consisting of the main and the trigger generator acts as a hybrid generator, which provides the SSHI/SSHC-algorithm with all necessary information. Combinations of generators of the same but also of different types can be realized. In Fig.9 is outlined a suited version of a hybrid generator consisting of the combination of a one-sided clamped swinging bimorph as main generator and a stationary inductive coil as trigger generator. A small magnetized pin is fixed on the bimorph and is dipped into the coil in the rhythm of the excitation frequency. This type is of interest because the signal of the main and the trigger signals a priori feature a phase shift of 90°. This results in an accurate determination of the trigger point. But also combinations of two bimorph generators are of interest, because they easily can be realized on one substrate.

EXPERIMENTAL

A schematic view of the hybrid generator consisting of a one sided clamped swinging piezoelectric bimorph as main generator and a stationary inductive coil as trigger generator can be seen in Fig. 9. The piezoelectric beam acts as a spring for the inductive system, so the movement of both generators is synchronized.

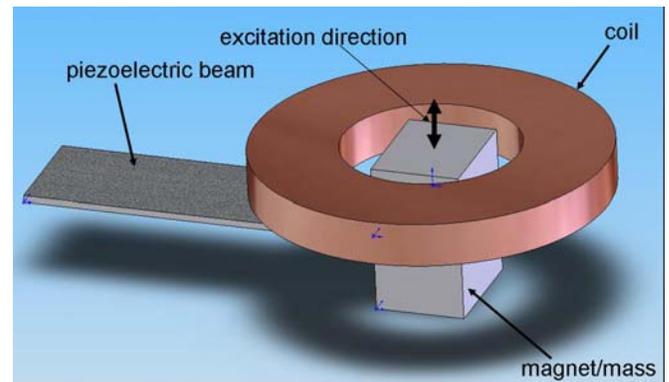


Fig. 9: “Hybrid” generator: The piezoelectric beam is used as generator and as mechanical spring for the inductive system at the same time.

A prototype of the hybrid generator is shown in Fig. 10. The piezoelectric bimorph is mounted on the generator casing and connected to a load resistor. As described a magnet is fixed at the end of the piezoelectric beam. It acts as a moving mass for the piezoelectric generator and induces a current in the coil at the same time. The coil is mounted on the casing over. If the closed casing, the magnet can dip into the coil in the rhythm of the excitation force.

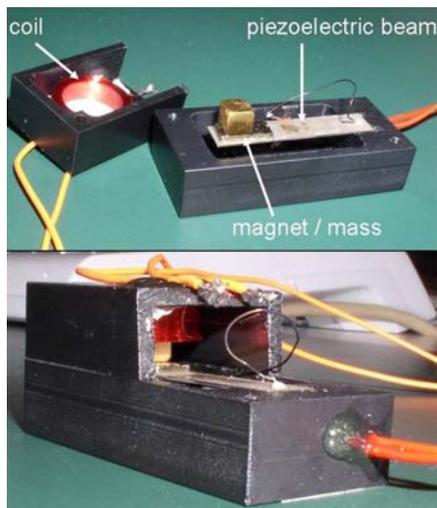


Fig. 10: Experimental Setup with piezoelectric beam, moving mass (magnet), coil and electrical connection. The upper section with the coil gets flipped and positioned diametrical opposed to the magnet.

For experimental characterization the hybrid generator was attached to a lab shaker. The applied vibration frequency was tuned to 130Hz, which is the resonant frequency of the piezoelectric generator. The result of the measurement is outlined in Fig. 11: A phase shift of 90° between the voltages produced by the piezoelectric bimorph and the inductive arrangement. Indeed, the position of the voltage maximum of the piezoelectric generator is concordant with the zero crossing point of the voltage produced by the inductive trigger generator.

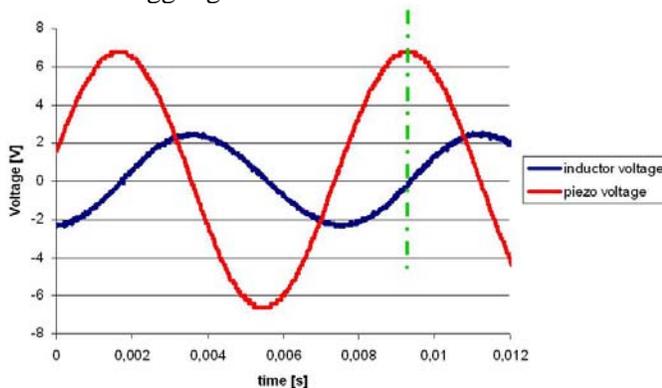


Fig. 11: Measurement of the voltage signals of the “hybrid” generator. The extremes of the piezoelectric bimorph voltage are synchronized with the zero crossing of the voltage from the inductive generator.

The inductive system remains unaffected by the sub-

sequent high impedance zero crossing comparator. Therefore the described arrangement of the hybrid generator yield the accurate trigger points demanded from the SSHI procedure.

CONCLUSION AND FUTURE WORK

A new approach for optimizing the power transfer from vibration driven energy scavengers to a storage element was presented. A first prototype for experimental characterization of a hybrid generator consisting of the combination of a one-sided clamped swinging bimorph as main generator and a stationary inductive coil as trigger generator was shown. The hybrid generator delivers signals that can be used to trigger a SSHI-interface to enhance the power transfer. Ongoing tasks consider the integration of the hybrid generator into the SSHI-System. The next important step will be to determine the profit in efficiency obtained with the hybrid generator.

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