Design of Boost Converter of Harvesting Piezoelectric Energy for Power Optimization without Sensor

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Abstract: The paper presents a model and operation of boost converter circuit for piezoelectric energy harvester circuit. Electrical input of boost converter working in continuous current mode for sensor less control. Experimental results show that the converter is controlled by very low voltage which maximizes the output power. The converter’s efficiency is about 92\% for the input voltages between 0.3V-1.0V and output power is 0.125W-1.26W. The presented circuit is also used for the power optimization of solar energy harvester circuit.

Keywords: AC-DC power conversion, DC-DC power conversion, energy conversion, piezoelectric devices and power generation.

I. INTRODUCTION

The conversion of mechanical energy into electrical energy by the use of piezoelectric material is not a recent idea. But piezoelectric electrical generators are very limited for very low power domain for the range of milliwatt range or below. This is depending on the mechanical properties of piezoelectric material: the acceptance of stresses is very large but the strains are very small. The high mechanical frequencies are necessary for the use these materials: ambient mechanical vibrations in the range of 0.1 Hz to 1 kHz. But the piezoelectric materials may work up to hundreds of kilohertz. Use of piezoelectric materials for the converting ambient mechanical shocks and vibrations into electrical energy [1]-[2]. Development of autonomous sensing nodes, powered by piezoelectric generators harvesting vibrational energy, usually lost or wasted is thus already possible with current technologies[2],[3],[4].Reduction in size and effective use of active materials required careful optimization of piezoelectric power Generators. They exhibit large effectiveness vibrational energy as a function of load electrical properties. In this area many optimizations circuit and control methods have been used [5]-[6]. This paper is proposed on power optimization of the piezoelectric energy harvesters. This is designed for harvesting mechanical energy resulting from local variations of acceleration. The power optimization is examined using a simple but comprehensive electromagnetic model of the generator. Operation modes of a boost converter used as power optimization interface are analyzed. The conditions for sensor less working are defined. Then practical implementation of a boost converter circuit with full bridge rectifier circuit for power optimization circuit with a sensor less control is demonstrated.

II. MODELING OF ELECTROMECHANICAL

Piezoelectric generators are designed for harvesting vibrational energy which is based on mechanical resonators, cantilever beams for instance. These structures exhibit narrow bands operation near a resonance frequency. The simplest for such devices is a single mode (spring, mass, damper) mechanical resonator coupled with the electrical circuit through electromechanical properties of the generator’s piezoelectric element, as depicted on Fig. 1.

Figure: 1. Electromechanical model of the piezoelectric generator.

In this figure, \( \omega_1 \) and \( \omega_2 \) represent respectively the mechanical displacements of the generator base and the dynamic mass in a Galilean referential. The dynamic mass \( M \) undergoes the action of its own inertia, a restoring force due to the mechanical structure stiffness \( K_S \), a viscous force due to the damper \( C \) and a force \( F_P \) due to the piezoelectric element. On the mechanical side, the piezoelectric element acts with its own stiffness plus a voltage controlled force, where \( V \) is the piezoelectric voltage. On the electrical side.

Fig: 2. Electrical circuit with terminal load modeled by a resistor.

The electromechanical model shown in fig.2 is converting the mechanical energy into electrical energy which is near to amount of 150mv-500mv. This electrical energy is applied to full bridge rectifier circuit for the
conversion of ac amount into the dc amount. This is the input voltage of the power optimization circuit. For the power optimization we are using the boost converter circuit.

III. POWER OPTIMIZATION CIRCUIT

In the section II the model describe the power of a piezoelectric generator is depends on the load. The value of the load is determined by the electromechanical characteristics of the generator and the vibration frequency of generator. Continuity of power supply must be ensured by a super capacitor. But these energy storage cells don’t exhibit the voltage/current properties of a resistor and they can’t intrinsically ensure an optimal power generation if directly connected to the rectifier output [5], has proposed to solve this power optimization problem using a dc–dc converter interleaved between the rectifier and the storage cell, shown in Fig. 2. They have shown that maximizing the power flowing into the storage cell can be achieved using adaptive controls similar to those used for maximizing the power from solar cells. For the optimal power point can be tracked by controlling the current and voltage, converter’s input average current is proportional to its input voltage and the average ratio of the converter is equal to the matching load resistance. This optimization technique can be considered as indirect because it is based on the knowledge of the matching load resistance. An important point for the design of very weak level of the “harvested” power controlled dc–dc converter is the, typically in the range of hundreds of microwatts. Thus, the control technique must be as simple as possible so that the control circuit consumption can be reduced to microwatts. This principle was first proposed by using boost converter [7], [8] and using by fly back converter [9].

IV. EXPERIMENTAL RESULTS

We are designing a boost converter circuit for energy harvesting in which applied electrical energy boosted using the following diagram (fig.5):

![Fig: 5. Experimental circuit diagram.](image)

In electrical side we are using:

a. **Rectifier circuit**: Rectifier circuit is used for the conversion of ac voltage in dc voltage and for the improvement of power extraction capability. The input of the rectifier circuit is 0.3-0.5v and we are using the schottky diode model no. IN5819. in the output we are using a 1µF capacitor. The input and output waveforms of rectifier circuit are shown in figure 6.
b. **Boost converter circuit:** In boost converter circuit the input supply is range of 0.3-0.5V and its output voltage is range of 9.3-9.8V. In the boost converter circuit we are using a inductor range of 110µH, the MOSFET irfz44 which is working as a switch, schottky diode IN5819, electrolytic capacitor 22µF and the load resistance 10k. we are applying a 3.5v level pulse waveform at gate of mosfet. The switching frequency of the circuit is 25 KHz and the duty cycle of the circuit is 80%. The efficiency of the converter is approximate 92% in this work. The input and output waveform of boost converter circuit is shown in figure 7 where yellow line shows the output of boost converter and another line shows the input waveform of boost converter.

The transient analysis of the Diode in5819 and MOSFET irfz44 is used in boost converter circuit are shown in figure 8 and 9 respectively.

**V. DISCUSSION**

In many sensors less control based system models are presented in open loop power optimization is not good with the generator’s parameters changes.

Energy storage is here ensured by a capacitor, but the presented power optimization circuit may also work with a battery or a super capacitor instead of a capacitor. However, variable output voltage is more constraining than fixed output voltage.

In improving in the efficiency and reducing the circuit size so first we reducing the switching frequency (for instance down to a kilohertz) in order to lowering the switching losses and the control circuit consumption, and then to reducing the duty cycle so that we are using SMT inductors of µH designed for power conversion. A slight improvement of the rectifier efficiency would be also possible using synchronous rectification techniques [10].Miniature Solar generators, also used for energy harvesting, have the same behaviors close to those of piezoelectric generators. Their powers are depend on the
load resistances [11], so optimization of these devices is also possible using the proposed circuit and control.

VI. CONCLUSION

This paper focuses on power optimization of piezoelectric energy harvesters, which convert vibrations into electrical energy. It is also used as a power source for automatic sensing devices. The power optimization analysis is based on a simple model of piezoelectric generator and an electrical circuit composed of a full bridge rectifier and voltage smoothing capacitor and resistor. This analysis is based on the values of the load resistance which provides maximum power. The study of the relation between the input voltage and input current of a boost converter shows that in discontinuous current mode this circuit intrinsically has the properties defined for power optimization, consumption of the control circuit of the boost converter, which requires sensors can be easily minimized. This study and the results presented here, which can be used for optimizing electromagnetic energy harvesters, may be helpful for the design of future integrated interfaces specialized in power optimization of solar generators.

REFERENCES


