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# Direct optimal resistance calculation MPPT algorithm for piezoelectric energy harvesting

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**Abstract**—We will explore in this paper a new MPPT algorithm that can find the MPP of a weakly coupled piezoelectric harvester with only a few measurements. This algorithm is fast compared to P&O algorithms and does not need the piezoelectric element to be in open-circuit. It is also independent of the harvesting techniques used here i.e. SEH, pSSHI and sSSHI.

## I. INTRODUCTION

Piezoelectric energy harvesting is a promising candidate for powering wireless sensor nodes for IoT. However, the power output of these devices heavily depends on the input vibrations amplitude and frequency. Algorithms for tracking the maximum power point (MPPT) are developed for permitting maximum power extraction. They are mandatory for extracting maximum power for most harvesting techniques like SEH, sSSHI and pSSHI. There are different categories of MPPT algorithms that can work for different harvesting techniques. Piezoelectric energy harvester are classically qualified as weakly or strongly electromechanically coupled.

For the weakly coupled harvesters, perturb and observe (P&O) and fractional open circuit voltage (FOCV) algorithms are mainly used thanks to their simplicity and ease of implementation. P&O algorithms constantly adapt the control setting of the implemented technique according to an increase or decrease of the harvested power [2]. P&O algorithms are often slow to reach maximum power because they incrementally change their control. FOCV algorithms are based on a periodic measurement of the piezoelectric voltage in open circuit condition [3]. For very weakly coupled harvesters, the maximum power is reached when the output DC voltage is equal to half the open circuit voltage. Nevertheless, FOCV algorithms require the piezoelectric harvester to be in open circuit for a minimum of half a mechanical period and do not transfer power during that time. Concerning the strongly coupled case, FOCV cannot be implemented because the relation between maximum power and output voltage depends on the electromechanical coupling  $k_m^2$ . P&O are working in a similar manner for strongly and weakly coupled harvesters and are greatly used for their simplicity. Look-up Tables (LUT) based algorithms are also implemented where the control of harvesting techniques for different frequencies are pre-calibrated and stored in memory.

MPPT are often compared based on their ability to reach the optimal setting, their speed and their electrical consumption, even if it can be complicated to decorrelate the consumption of the MPPT algorithm and the one of the system. They can also be

compared on their robustness related to the vibration amplitude/frequency shift and/or the generator aging [4].

In this paper, we focus on weakly coupled piezoelectric vibration energy harvesters. We propose an MPPT algorithm that theoretically finds the MPP with only four voltage measurements while harvesting energy and which is independent of the harvesting technique.

## II. MODEL

Weakly coupled piezoelectric harvesters can be modeled at resonance by a current source in parallel with a capacitor as depicted in Fig. 1. In this case, the backward coupling between the electrical and the mechanical part is neglected. The goal here is to use a new algorithm for weakly coupled harvesters for SEH, sSSHI and pSSHI. In order to verify the performance of the proposed algorithm, we consider that a buck-boost converter is used for resistive impedance matching, as shown in Fig. 1. The dotted SSHI box represents a possible SSHI-like inversion switch, including its inductance.

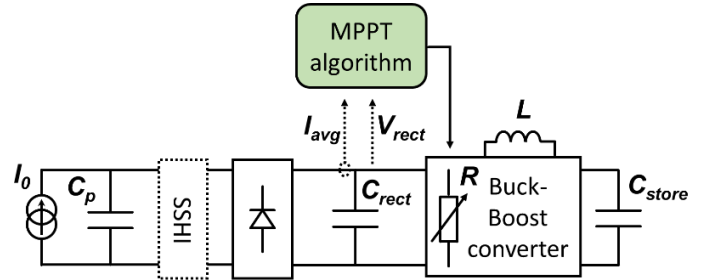


FIGURE 1 : STRUCTURE FOR RESISTIVE IMPEDANCE ADAPTATION

DC/DC converters are commonly used for resistive impedance matching, the buck-boost technology is often used thanks to the independence of its input voltage  $V_{rect}$  with the input resistance  $R$  when used in discontinuous conduction mode. Indeed, the relation between its input resistance and the control of the associated switch is Eq. (1).

$$R = \frac{2L}{f_{sw}t_1^2} \quad (1)$$

$L$  is the inductance of the buck-boost,  $f_{sw}$  is the control frequency of the switch and  $t_1$  is the on time of the switch.

After measuring the optimal resistance (see next part), the main goal of the MPPT algorithm is to adjust the equivalent input resistance of the converter to match the optimal resistance.

## III. OPTIMAL RESISTANCE MEASUREMENT

## A. Working principle

Our optimal resistance measurement method is based on four voltage measurements across the smoothing capacitor  $C_{rect}$ . By doing two close measurements before and right after the conduction of the full bridge rectifier, the average current flowing through  $C_{rect}$  ( $I_{avg} = C_{rect} \frac{\Delta V_{rect}}{\Delta t}$ ) can be determined. The same two measurements are performed a second time at another voltage point. This way, a second point is obtained on the average current / voltage characteristic (Fig. 2). As the current versus voltage characteristics of the piezoelectric harvester is linear, we use linear regression to obtain its open circuit voltage and average short circuit current. This method is similar to the one in [5] but contrary to the latter, we do not only use the open circuit voltage but also the average short circuit current to obtain  $R_{opt}$  as in Eq. (2). It is then possible to control the buck-boost converter with  $R_{opt}$  as input resistance.

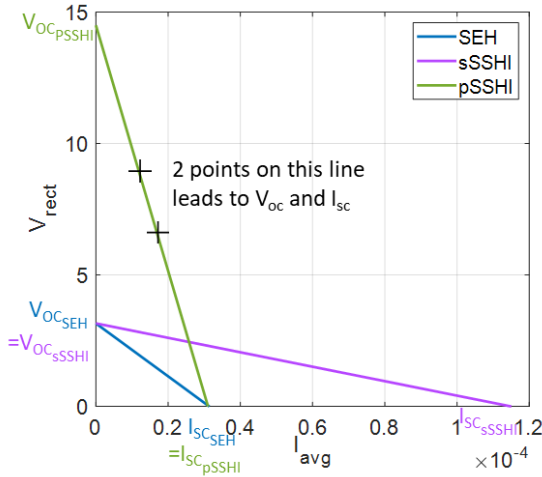


FIGURE 2 : SIMULATED LINEAR CHARACTERISTICS OF CURRENT AND VOLTAGE ON C<sub>RECT</sub> FOR DIFFERENT TECHNIQUES (Q=7, I<sub>0</sub>=5E-5 A, C<sub>P</sub>=50E-9 F, F=50 Hz)

$$R_{opt_{technique}} = \frac{V_{OC_{technique}}}{I_{SC_{technique}}} \quad (2)$$

Optimal resistance for SEH, sSSHI and pSSHI are well known in the state of the art. We will give here the expressions of  $V_{OC}$  and  $I_{SC}$  that can lead to  $R_{opt}$  for all techniques : Eq. (3) to (6).  $I_{avg}$  is the average rectified current going into capacitor  $C_{rect}$ , hence it is  $\frac{2}{\pi}$  times the amplitude of the sinusoidal current going into the full bridge rectifier.  $\gamma$  is the inversion factor of the SSHI block.

$$V_{OC_{SEH}} = V_{OC_{sSSHI}} = V_{OC_{piezo}} \quad (3)$$

$$V_{OC_{pSSHI}} = 2 \frac{V_{OC_{piezo}}}{(1 - \gamma)} \quad (4)$$

$$I_{SC_{SEH}} = I_{SC_{pSSHI}} = \frac{2}{\pi} I_0 \quad (5)$$

$$I_{SC_{sSSHI}} = \frac{2 I_0 (1 + \gamma)}{(1 - \gamma)} \quad (6)$$

Each characteristic line is plotted for a single operating point i.e. fixed vibration frequency and amplitude (fixed frequency and fixed  $I_0$  here). It means that measurements should be temporally close but with a sufficient difference in voltage for the linear regression to be precise (see section III.B). With the proposed algorithm, measuring the MPP does not need the piezoelectric element to be in open circuit since it keeps harvesting energy while measuring. Obtaining the MPP is also fast compared to P&O algorithms. Moreover, the obtained  $R_{opt}$  is independent of the harvesting technique, the proposed MPPT algorithm will work identically for each harvesting technique.

## B. Sizing of the system

This algorithm efficiency depends in particular on the choice of the capacitor  $C_{rect}$ . Choosing a large capacitance value allows the current extraction point to stay a long time at the chosen power point (ideally the MPP) because  $V_{rect}$  varies slowly over time. A small capacitor will be handy for rapidly measuring  $V_{rect}$  and  $I_{avg}$  while working with a high  $\Delta V_{rect}$ , which increases the accuracy of the measurement (e.g with a 12 bits resolution ADC). A compromise must therefore be found between speed, accuracy and power consumption of the complete system.

## IV. CONCLUSION

This work shows a new MPPT algorithm that allows direct measurement of the optimal resistance for impedance matching while harvesting energy. To the best of the author knowledge, this algorithm has never been proposed in the state of the art. Future work will focus on using this algorithm on strongly coupled piezoelectric beams.

## REFERENCES

- [1] A. Brenes, A. Morel, J. Juillard, E. Lefeuvre, and A. Badel, "Maximum power point of piezoelectric energy harvesters: a review of optimality condition for electrical tuning," *Smart Mater. Struct.*, vol. 29, no. 3, p. 033001, Mar. 2020, doi: 10.1088/1361-665X/ab6484.
- [2] S. Li, A. Roy, and B. H. Calhoun, "A Piezoelectric Energy-Harvesting System with Parallel-SSHI Rectifier and Integrated MPPT Achieving 417% Energy-Extraction Improvement and 97% Tracking Efficiency," in *2019 Symposium on VLSI Circuits*, Jun. 2019, pp. C324–C325. doi: 10.23919/VLSIC.2019.8778144.
- [3] M. Shim, J. Kim, J. Jeong, S. Park, and C. Kim, "Self-Powered 30  $\mu$ W to 10 mW Piezoelectric Energy Harvesting System With 9.09 ms/V Maximum Power Point Tracking Time," *IEEE Journal of Solid-State Circuits*, vol. 50, no. 10, pp. 2367–2379, Oct. 2015, doi: 10.1109/JSSC.2015.2456880.
- [4] A. Morel, "Interfaces électriques adaptatives dynamiquement au spectre fréquentiel pour la récupération d'énergie vibratoire large bande," *Theses, Université Savoie Mont Blanc*, 2020. Accessed: Mar. 22, 2021. [Online]. Available: <https://hal.archives-ouvertes.fr/tel-03099900>
- [5] Y. Hu, I. Chen, and T. Tsai, "A piezoelectric vibration energy harvesting system with improved power extraction capability," in *2016 IEEE Asian Solid-State Circuits Conference (A-SSCC)*, Nov. 2016, pp. 305–308. doi: 10.1109/ASSCC.2016.7844196.