A low power and efficient microcontroller-based extraction circuit for HVAC applications

Pierre Gasnier, Maxime Gallardo, Rammouz Ramzy, Nicolas Garraud, Louis Araouzos, Alexandra Garraud, J-P Gros

A low power and efficient microcontroller-based extraction circuit for HVAC applications

Pierre GASNIER[1], Maxime GALLARDO[2], Ramzy RAMMOUZ[1], Nicolas GARRAUD[1], Louis ARAOUZOS[3], Alexandra GARRAUD[3], Jean-Philippe GROS[1]
[1]CEA-Leti, Université Grenoble Alpes, F-38000 Grenoble, France
[2]SERMA Ingenierie, F-38000 Grenoble, France and [3]Enerbee Technology, F2A Group, F-38000 Grenoble, France
e-mail: pierre.gasnier@cea.fr

***Abstract*—In this paper, we report a low power implementation of a Power Management Circuit (PMC) performed by means of a microcontroller unit (MCU) surrounded by discrete components. In the context of HVAC applications with the aim of converting rotational movements into electrical energy, a non-linear extraction technique is implemented by controlling a Flyback converter at the maximum voltage of a magnetoelectric harvester. Compared with the Standard Energy Harvesting (SEH) interface, a power gain up to 1.75 was measured at a frequency of 47 Hz and a Flyback efficiency up to 80% for an output power of 0.5 mW. This architecture contributes to increase the versatility of PMCs addressing lowly-coupled piezoelectric harvesters (PEHs).**

***Index Terms*—Power management circuits, energy harvester, microcontroller, piezoelectric, HVAC, magnetoelectric**

I. Introduction

This work deals with a macroscopic magnetoelectric harvester (i.e. including magnetostrictive and piezoelectric materials) to convert air flows into electrical energy for HVAC applications. For the considered application, we proposed a PMC adressing rotation frequencies down to hundred's of rpm (a few hertz) to ∼3000 rpm (∼50 Hz). Indeed, PMCs implementing efficient extraction techniques are important elements to optimize the electrical conversion stage such an energy harvesting system and particularly for PEHs. The harvester's details being not in the scope of this paper, we will consider here that a PEH having a intrinsic capacitance C_p from a dozen to a few hundreds of nF is alternatively compressed and stretched in quasi-static mode thanks to a horizontal-axis wind turbine. In this paper, we report the implementation of the Multi-Shot Synchronous Electric Charge Extraction (MS-SECE) with a MCU. The goal of the paper is to show that implementing efficient non-linear extraction techniques controlled by MCUs is an interesting and more flexible alternative to ASICs.

II. Extraction technique

The proposed PMC is based on the MS-SECE extraction technique [1], an improved version of the well-known SECE [2] technique. The SECE is theoretically up to four times more efficient than the standard energy harvesting interface (SEH), i.e. a full bridge rectifier (FBR) at its optimal voltage, while its extracted power is independent on the voltage across the storage element. Paing *et al.* [3] have already proven the feasibily of powering the SECE technique with a MCU, but as far as we know no MS-SECE has ever been implemented with such component. The energy extraction happens at the same moment in the cycle as that of the SECE, i.e. at the maximum of the PEH voltage. However, in the case of a MS-SECE, the energy is extracted in N successive "shots", each transferring the same amount of energy, instead of a single transfer. By successively driving the primary (K_p) and secondary (K_s) MOSFETs of the Flyback converter, the MS-SECE technique enables to i) improve the efficiency of the energy transfer as compared with SECE or ii) makes it possible to reduce the volume of the PMC at constant efficiency. For the power path, a Flyback converter is used, its coupled inductor allows to easily control the two MOSFETs switches. The overall schematic of the proposed PMC is depicted in Fig. 1, showing the power path (FBR and flyback), the Maximum Voltage Detector block mainly used to detect the maximum PEH voltage and the MCU implementing the MS-SECE.

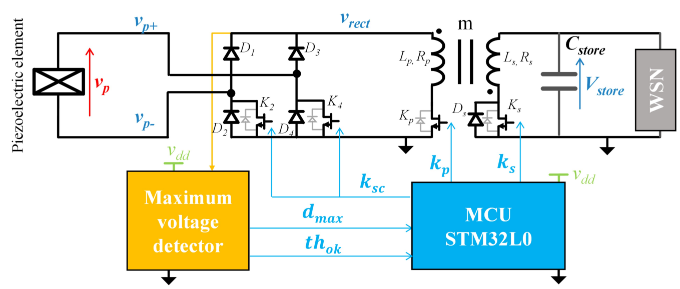

Fig. 1. Overall architecture of the PMC (cold-start function not depicted).

The important signals of the proposed circuit are depicted in Fig. 2. One can note that the PEH is discharged in N successive shots after the maximum detection (d_{max}) goes high. Because parasitic oscillations of v_p can occur in a real situation (noise, vibration), the extremum detections are ignored during the MS-SECE phase and when v_p goes below a fixed threshold, avoiding any PEH discharges at inopportune moments. Two additionnal MOSFETs (K_2) and (K_4) are used to short the PEH right after its discharge for the next deformation to start at $v_p = 0$, which enhances the harvestable power particularly at very low frequencies ($f_e < 10$ Hz).

III. Implementation

We used a low-power MCU (STM32L011) to implement the MS-SECE technique associated with a low level programming to optimize the power consumption of the system. Most of

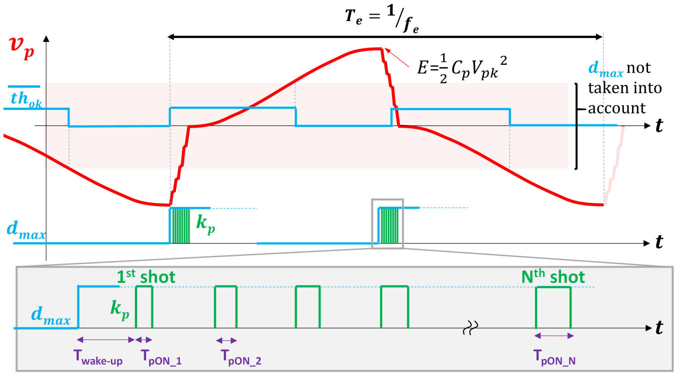

Fig. 2. Ideal voltage waveforms of the circuit showing two N-shots MS-SECE discharges performed during a complete electrical period T_e. The control of K_s for the Flyback secondary phase is not depicted on this graph.

the time, the MCU is in STOP mode until it wakes up to a RUN mode using its 16 MHz internal oscillator to precisely control K_p and K_s with a $\sim$60 ns resolution. Right after the N-shots discharge, the MCU gets back to its STOP mode and inactivates the oscillator. A second, low frequency and imprecise, $\sim$37 kHz clock is however used all the time with the aim of generating the short-circuit duration to drive K_2 and K_4 with the control signal k_{sc}. For the "Maximum Voltage Detector" block, we employed a RC-differentiator followed by a zero-crossing function based on a comparator (MAX9119) to detect the maximum voltage of v_p. The threshold detection block is implemented with a low power comparator (TLV3691-TI) surrounded by discrete components.

IV. Results

The PMC has been tested on a preliminary version of an Enerbee Technology's harvester. Its rotation frequency was set on a dedicated test bench by a brushed DC geared motor, leading to an electrical frequency f_e in the $[1-50\,\text{Hz}]$ range. The peak open circuit voltage V_{pk} of the PEH was 19.4 V (independently from f_e) and its capacitance $C_p = 36.5\,\text{nF}$. Fig. 3 shows a picture in inset of the test PCB embedding all the necessary components with additional test points. Concerning the PCB of the proposed PMC, we estimated that it could be reduced to a 3cm×3cm area. Fig 3 also shows the output power of the circuit measured on C_{store} (i.e. for various V_{store}) at $f_e = 30\,\text{Hz}$ ($P_{out} = 300\,\mu\text{W}$) leading for this specific case to a power gain of 1.6 compared to an optimized SEH technique ($V_{rect} = 5\,\text{V}$). We also observed that the power gain was around 1.4 at $f_e = 8\,\text{Hz}$ ($P_{out} = 60\,\mu\text{W}$) and 1.75 at $f_e = 75\,\text{Hz}$ ($P_{out} = 500\,\mu\text{W}$). At $V_{rect} = 3\,\text{V}$, a gain of 2.14 has been measured at $f_e = 75\,\text{Hz}$. We measured a Flyback efficiency around 75%-80% for a 16-shot discharge. The attentive reader will notice that the gain compared to a SEH technique is quite low compared with the theoretical gain of 4 of the SECE, which is not entirely explain by the Flyback efficiency. Indeed, we observed that V_{pk}, when the MS-SECE is activated, is not increased by a factor of 2 as expected, but rather by a factor of 1.1 to 1.6 depending on f_e. This is probably due to the fact that the material's deformation amplitude is not fully imposed, particularly during the sudden MS-SECE discharge. A variation of the PEH's capacitance during its deformation could also explain such behavior.

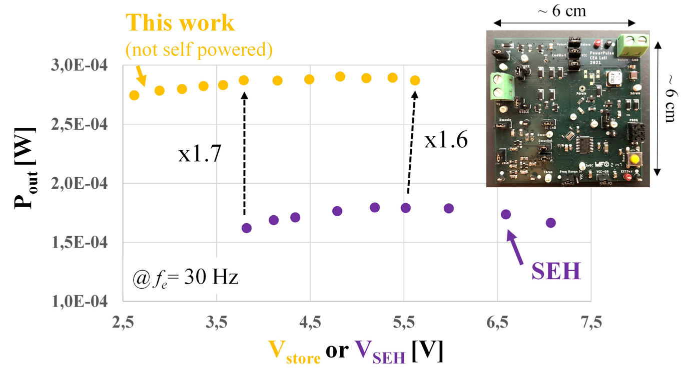

Fig. 3. Electrical output power: proposed PMC vs SEH technique at a frequency of 30 Hz. Inset: test PCB of the proposed PMC.

The power consumption of the circuit is dependent on the input frequency and is around 7 μW/Hz for a 16-shot discharge performed 2 times per electrical period. Finally, we observed a significant increased of the harvestable (and harvested) power in the low frequency range ($f_e < 10\,\text{Hz}$) when the short circuit function is activated. For example, the harvestable power was increased by 1.3 at $f_e = 8\,\text{Hz}$ with this additional function. For frequencies higher than $f_e = 10\,\text{Hz}$, the power improvement of the short circuit becomes insignificant. This function must be dynamically adapted (i.e. the short circuit duration) in operation to fit the large frequency range of the targeted application.

V. Discussions

To the authors' knowledge, this is the first reported MCU-based MS-SECE PMC. Such a PMC is versatile to any change of harvester's characteristics (capacitance, PEH output voltage) and seems very well suited for applications that have not yet reached a mass market (often justifying ASICs). As a perspective, a dynamic optimisation of the short-circuit duration and the number of shots of the MS-SECE (efficiency vs power consumption) in operation must be investigated. These potential improvements open a way towards an optimization with, for instance, intelligent Maximum Power Point Tracking algorithms implemented by the MCU in a very low power manner. Finally, integrating the PMC functions and the sensor system within the same MCU appears to be an interesting optimization from a cost and area standpoint.

References

[1] P. Gasnier, J. Willemin, S. Boisseau, G. Despesse, C. Condemine, G. Gouvernet, and J.-J. Chaillout, "An autonomous piezoelectric energy harvesting IC based on a synchronous multi-shot technique," *IEEE Journal of Solid-State Circuits*, vol. 49, no. 7, pp. 1561–1570, 2014.

[2] E. Lefeuvre, A. Badel, C. Richard, and D. Guyomar, "Piezoelectric Energy Harvesting Device Optimization by Synchronous Electric Charge Extraction," *Journal of Intelligent Material Systems and Structures*, vol. 16, no. 10, pp. 865–876, Oct. 2005.

[3] T. Paing and R. Zane, "Design and optimization of an adaptive non-linear piezoelectric energy harvester," in *2011 Twenty-Sixth Annual IEEE APEC*, Mar. 2011, pp. 412–418.