ID09 CONSUMPTION EVALUATION OF A RELAXATION OSCILLATOR AS A CONTROL SAMPLING CIRCUIT FOR FAST-TRACKING FOCV-MPPT CIRCUITS IN WAVE ENERGY CONVERTERS

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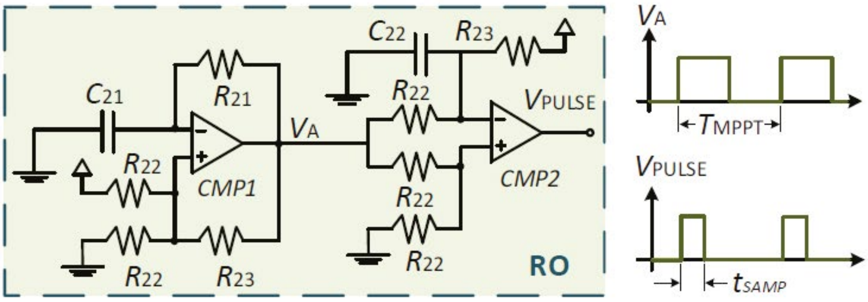
ABSTRACT

Energy harvesting (EH) sources require a power management unit (PMU) with maximum power point tracking (MPPT) functionalities to maximize the energy generation. One simple MPPT approach, widely used in low-power EH applications and thoroughly explained in [1], is the fractional open circuit voltage (FOCV) method. In this method, maximum energy is harvested by fixing the output voltage of the EH source to the maximum power point (MPP) voltage (V_{MPP}), which is a percentage of its open circuit voltage (V_{OC}). Typically, V_{OC} is periodically measured (at a sampling period of T_{MPPT}) by momentarily disconnecting the EH source from the PMU during a sampling time (t_{SAMP}) and storing the V_{OC} corresponding to the new environmental conditions. Some sources, such as wave energy converters (WEC), require fast tracking of the MPP because V_{OC} shows relatively rapid variations. For example, [2] presents a WEC with V_{OC} oscillating at around 1.8 Hz, which is fast-varying compared to other types of EH sources, e.g. solar and thermal. However, commercial PMUs fail to provide these fast-tracking methods.

In [3] we designed a custom, fast-tracking FOCV-MPPT circuit, and demonstrated that by sampling 15 times higher than the EH source's frequency (f_{EH}), 99% of the maximum energy can be harvested. The circuit was based on a commercial MPPT, the ADP5092 IC, with additional low-power circuitry to greatly reduce t_{SAMP} and T_{MPPT}. Later, in [4] we presented a low-power relaxation oscillator (RO) that generates the pulse signal (V_{PULSE}) to control the sampling process of V_{OC}. Fig. 1 shows the RO circuit with a qualitative representation of V_{PULSE}.



$$T_{\mathbf{MPPT}} = 2R_{21}C_{21}\ln\left(\frac{m+1}{m}\right) \tag{1}$$

$$t_{\mathbf{SAMP}} = \frac{mR_{22}C_{22}}{m+1}\ln\left(\frac{2m}{m+1}\right) \tag{2}$$

$$m = \frac{R_{23}}{R_{22}} \tag{3}$$

Fig. 1. Relaxation oscillator (RO) for the generation of VPULSE.

The power consumption of the RO must be lower than the power gain achieved by speeding up the sampling rate (f_{MPPT} = 1/ T_{MPPT}) of the MPPT. Therefore, the power consumption of the RO was assessed with the following values; R_{22} = 1 MΩ, R_{23} = 5 MΩ, C_{21} = 33 nF and C_{22} = 1.2 nF. The two comparators (CMP1 and CMP2) were implemented with the MCP6542 IC. Six different values for R_{21} were used to evaluate its consumption at different sampling conditions, as a change in this resistor modify T_{MPPT} according to the equations (1) - (3) presented in [4]. Resulting nominal values of T_{MPPT} and f_{MPPT} are reported in Table 1, with t_{SAMP} fixed to 0.5 ms according to (2). A 10 kΩ shunt resistor of 0.1% tolerance was used to measure the current consumption of the RO circuit, which was supplied at 3.8 V.

R_{21}	1	2	5.1	10	14.8	29.8
$T_{MPPT\,[ms]}$	12.0	24.1	61.4	120.3	178.1	358.6
$f_{MPPT\,[Hz]}$	83.3	41.5	16.3	8.3	5.6	2.8

Table 1. Nominal values for R_{21}, T_{MPPT} and f_{MPPT} on the consumption test of the sampling circuitry.

Fig. 2 (top) shows the current consumption profile of the RO at T_{MPPT} = 61.4 ms (R_{21} = 5.1 MΩ) with an average value of 4.31 µA (16.3 µW). As can be seen, there are three different levels. When V_A is high and VPULSE is low, current consumption is around 5 µA. When both V_A and V_{PULSE} are low, it is around 3 µA. Finally, a 10 µA current peak is found when V_A and V_{PULSE} are high, corresponding to the sampling time of V_{OC} (t_{SAMP}). By increasing f_{MPPT}, T_{MPPT} decreases whereas t_{SAMP} is kept fix. This leads to a percentual time increase of the current peaks and thus to an increase of the average current consumption. This is shown in Fig. 2 (bottom), where the average power consumption is represented as a function of f_{MPPT}. As can be seen, power consumption linearly increases with f_{MPPT}, varying from 15 to 20 µW.

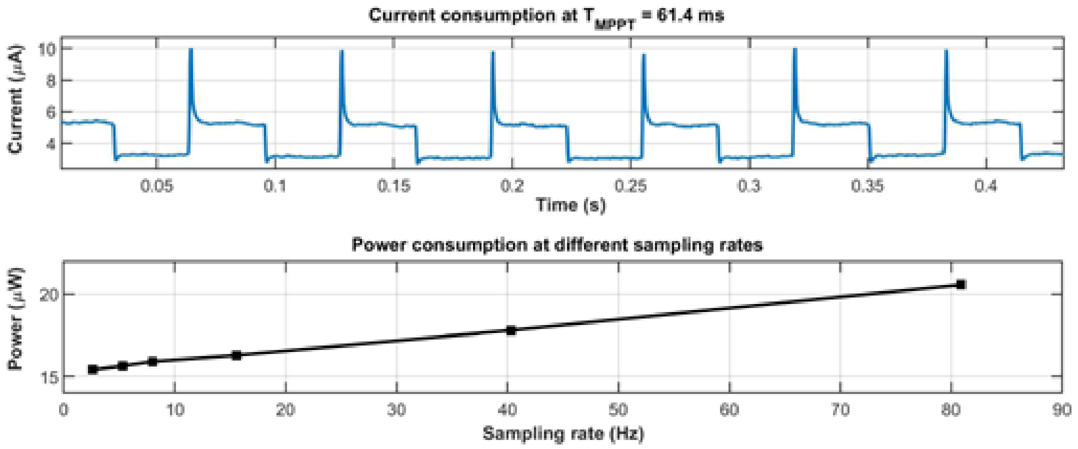


Fig. 2. Consumption of the RO. Top: current consumption at T_{MPPT} = 61.4 ms. Bottom, average power consumption at different sampling rates.

Results in [3] show a small-size WEC excited in a linear-shaker and report that a fast-sampling circuit (f_{MPPT} = 60 Hz) provided a useful power of 7.68 mW whereas a low-sampling circuit (T_{MPPT} = 16 s) just 6.1 mW; thus, a power gain of 1.57 mW was achieved. The same WEC was deployed at the sea in [4]. In that case, the fast sampling-circuit (f_{MPPT} = 21 Hz), which included the power waste of the RO, provided 218 μW whereas the low-sampling circuit just 80 μW. Given the consumption of the RO at the tested sampling rates is below 20 μW, its use is worthwhile.

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