



EUROSENSORS 2014, the XXVIII edition of the conference series

Improving the efficiency of PV low-power processing circuits by selecting an optimal inductor current of the DC/DC converter

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Abstract

In the context of autonomous sensors powered by small-size photovoltaic (PV) panels, this work analyses how the efficiency of DC/DC-converter-based power processing circuits can be improved by an appropriate selection of the inductor current that transfers the energy from the PV panel to a storage unit. Each component of power losses (fixed, conduction and switching losses) involved in the DC/DC converter specifically depends on the average inductor current so that there is an optimal value of this current that causes minimal losses and, hence, maximum efficiency. Such an idea has been tested experimentally using two commercial DC/DC converters whose average inductor current is adjustable. Experimental results show that the efficiency can be improved up to 12 % by selecting an optimal value of that current, which is around 300-350 mA for such DC/DC converters.

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Peer-review under responsibility of the scientific committee of Eurosenors 2014

Keywords: DC/DC converter; efficiency; photovoltaic panel; power processing circuit.

1. Introduction

The power extracted from a PV panel depends on the operating voltage and there is a maximum power point (MPP) with the corresponding operating voltage (V_{MPP}) that changes with irradiance level and temperature. Low-power PV panels are generally connected to power processing circuits that have two main blocks: a tracking controller that determines V_{MPP} using diverse methods [1-4], and a switching DC/DC converter. Fig. 1a shows a particular implementation using a synchronous boost converter (with an inductor, L , and two MOSFET power transistors, MN and MP) operating in burst mode, where a comparator (with a hysteresis of $\pm V_{hys}$) activates the converter just when the input voltage (v_{in}) exceeds $V_{MPP} + V_{hys}$, as shown in Fig. 1b. While the converter is activated,

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the energy harvested and accumulated in the input capacitor (C_{in}) is transferred through an inductor current (i_L) whose average value equals I_{L0} to a storage unit (such as a rechargeable battery or a supercapacitor) that powers the sensor electronics. Therefore, v_{in} decreases and when it reaches $V_{MPP} - V_{hys}$, the converter is deactivated and the process starts again. Using this operating principle, the PV panel continuously operates around the MPP and the converter remains inactive most of the time, thus improving the efficiency. To date, however, the impact of the value of I_{L0} on the efficiency of the converter when performing such an energy transfer has not been assessed. Note that several power losses (fixed, conduction and switching losses [5]) are involved in that energy transfer and each of them specifically depends on I_{L0} . Therefore, we can expect an optimal value of I_{L0} , which is verified herein by reporting a set of experimental results.

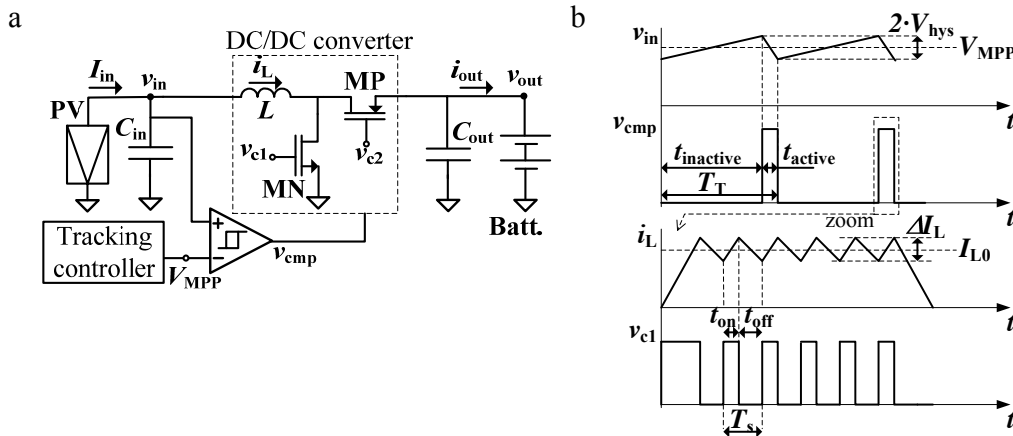


Fig. 1. (a) Power processing circuit for a PV panel based on a DC/DC converter. (b) Waveforms of interest from the circuit in Fig. 1a.

2. Materials and method

The effects of I_{L0} on the efficiency of the circuit in Fig. 1a have been tested experimentally through the set-up shown in Fig. 2 using two commercial boost DC/DC converters (LTC3125 and TPS61252) whose I_{L0} can be adjusted externally by a resistor (R_i). The main features of such DC/DC converters are summarized in Table 1.

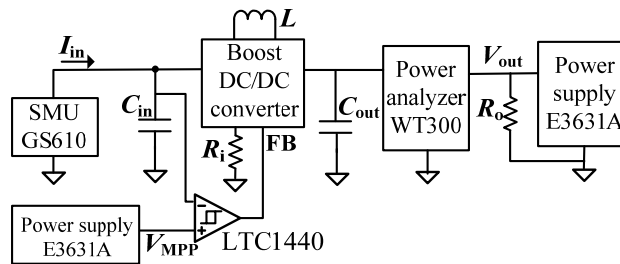


Fig. 2. Set-up employed to test the efficiency of the circuit in Fig. 1a.

Table 1. Features of the commercial DC/DC converters.

Feature	LTC3125 (Linear Technology)	TPS61252 (Texas Instruments)
Operating frequency	1.6 MHz	3.25 MHz
Range of I_{L0}	[200, 1000] mA	[100, 1500] mA
Range of input voltage	[1.8, 5.5] V	[2.3, 6.0] V
Range of output voltage	[2.0, 5.25] V	[3.0, 6.5] V
Value of L	4.7 μ H	2.2 μ H

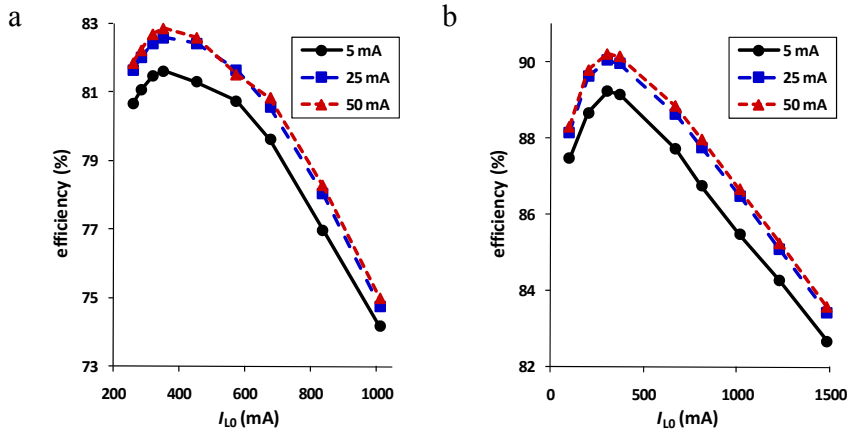


Fig. 3. Efficiency of the circuit using (a) LTC3125 and (b) TPS61252 versus I_{L0} , for different values of I_{in} when $V_{MPP} = 2.5\text{ V}$ and $V_{out} = 5\text{ V}$.

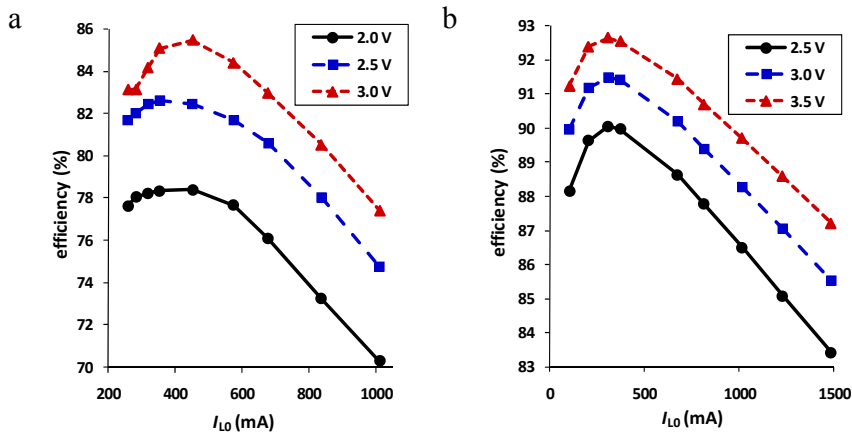


Fig. 4. Efficiency of the circuit using (a) LTC3125 and (b) TPS61252 versus I_{L0} , for different values of V_{MPP} when $I_{in} = 25\text{ mA}$ and $V_{out} = 5\text{ V}$.

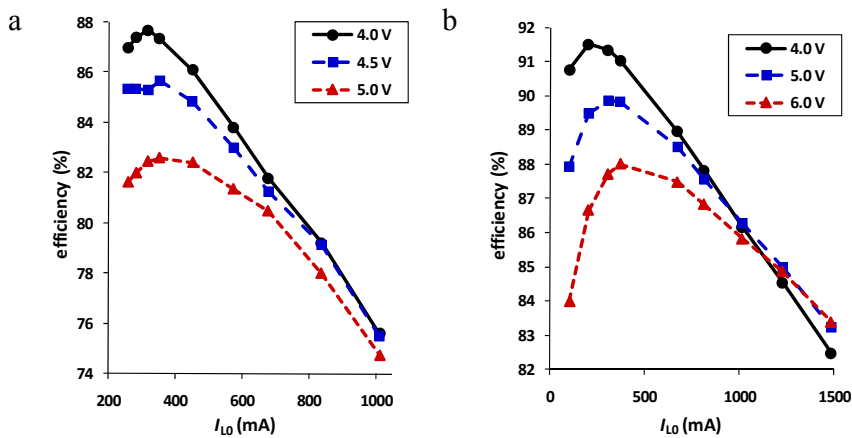


Fig. 5. Efficiency of the circuit using (a) LTC3125 and (b) TPS61252 versus I_{L0} , for different values of V_{out} when $I_{in} = 25\text{ mA}$ and $V_{MPP} = 2.5\text{ V}$.

In the set-up shown in Fig. 2, a source-measurement unit (Yokogawa GS610) was used to emulate the PV panel by supplying a DC current (I_{in}). Two DC voltage sources (Agilent E3631A) were respectively used to provide the operating voltage (V_{MPP}) and to emulate a rechargeable battery providing an output voltage V_{out} ; the latter had a resistor (R_0) in parallel so as to be able to operate in the fourth quadrant. The comparator was an ultralow-power model (LTC1440) with a hysteresis of ± 50 mV whose output was connected to the voltage feedback input (FB) of the DC/DC converter [3,4]. C_{in} was a 1-mF tantalum capacitor for both converters, whereas C_{out} was a 4.4-mF tantalum capacitor for the LTC3125 and a 44- μ F ceramic capacitor for the TPS61252, as recommended in their datasheets; all capacitors had a low ESR. The input power was calculated as $V_{MPP}I_{in}$ (both quantities were measured by a digital multimeter), whereas the average output power was measured by a power analyzer (Yokogawa WT3000) with a sampling frequency of 200 kSa/s and an update rate of 5 s.

3. Experimental results

Using the materials and method explained in Section 2, we have carried out several experiments to observe the effects of I_{L0} on the efficiency of the circuit in Fig. 1a. First of all, Fig. 3 shows for both DC/DC converters how the efficiency depends on I_{L0} for different values of I_{in} when constant values of V_{MPP} ($= 2.5$ V) and V_{out} ($= 5$ V) were applied. The optimal value of I_{L0} , which was independent of I_{in} , was around 350 mA for the LTC3125 and 300 mA for the TPS61252. With respect to the worst case (i.e. maximum value of I_{L0}), the efficiency increased about 8 % for the LTC3125 and 7 % for the TPS61252 when the optimal value of I_{L0} was used. Moreover, the efficiency slightly increased with I_{in} .

Second of all, Fig. 4 shows how the efficiency depends on I_{L0} for different values of V_{MPP} when constant values of I_{in} ($= 25$ mA) and V_{out} ($= 5$ V) were used. The optimal value of I_{L0} , which was quite independent of V_{MPP} except for the LTC3125 when $V_{MPP} = 3$ V, was again about 350 mA for the LTC3125 and 300 mA for the TPS61252. In comparison with the worst case, the efficiency also improved around 8 % for the LTC3125 and 7 % for the TPS61252 when the optimal value of I_{L0} was applied. In addition, the efficiency clearly increased with V_{MPP} .

Finally, Fig. 5 shows how the efficiency depends on I_{L0} for different values of V_{out} when constant values of I_{in} ($= 25$ mA) and V_{MPP} ($= 2.5$ V) were applied. Here, the optimal value of I_{L0} increased with V_{out} : from 300 mA to 350 mA for the LTC3125, and from 200 mA to 400 mA for the TPS61252. The fact of using the optimal value of I_{L0} improved the efficiency up to 12 % for the LTC3125 and 10 % for the TPS61252. Furthermore, the efficiency clearly decreased with V_{out} ; this is because some power loss components (such as the switching losses due to parasitic capacitances) increase with V_{out} .

4. Conclusions

A set of experimental results has demonstrated that there is an optimal value of I_{L0} (around 300-350 mA for the DC/DC converters under test) to carry out the energy transfer from a PV panel to a storage unit. When this optimal current is applied, the efficiency of the power processing circuit can increase up to 12 % and, therefore, this is a simple but effective way to improve the autonomy of sensors powered by small-size PV panels.

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