Ben Gurion University of the Negev
Department of Electrical and Computer Engineering
Power Electronic Group

Senior Project: p-2012-068
"Optimized converter of low power for solar cells"

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Abstract

The field of solar energy has been a focus of extensive research in recent years, due to its outstanding advantages. These advantages result mainly from the ready availability of sunlight and from the cleanliness of solar energy production. Furthermore, the production of electricity from the sun can be performed locally.

These advantages are particularly significant when a solar source is used in remote, off-grid systems. These are independent systems designed for local use, such as in isolated locations or mobile installations. However, utilizing a solar source in these systems requires the employment of a voltage conversion unit.

This project focuses on the development of such a voltage conversion unit, which will include a switched-capacitor DC-DC converter (SCC). This type of converter can be fully implemented by means of mass-production, cheap and miniature VLSI technology. Furthermore, it is possible to fabricate both the solar cell and a converter on the same die. A particular advantage of the proposed SCC is its multiple high-efficiency conversion ratios. This characteristic allows the operation of the Maximum-Power-Point-Tracking (MPPT) control mechanism. The MPPT ensures good performance in varying working conditions.

The complete system design consists of a single solar cell, a SCC converter with a MPPT mechanism and a battery, which is charged by the converter and serves as a power source for the consumer.

This project includes the design, construction and testing of a model system and provides the groundwork for the future development of a full VLSI implementation.

SCC converter

SCC converters working in Binary and Fibonacci topologies have been presented in [1], [2] and [3].
This type of converter can implement various conversion ratios, depending on the number of switched capacitor stages, and can achieve high-efficiency conversion. An example of a 3-stage converter and its conversion ratios is presented in Figure1 and Table 1.

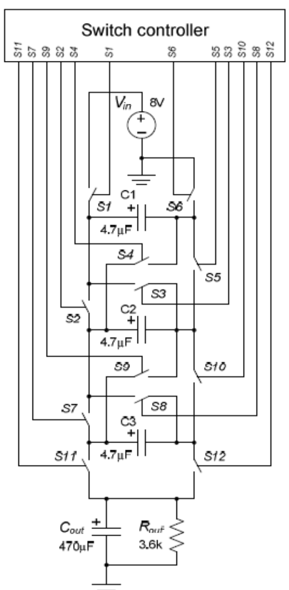

Figure 1: 3 stage SCC (from [1])

Numeric representation Method	Conversion ratio (up-conversion)
EXB	8/1
SFB	5/1
EXB	8/2
SFB	3/1
EXB	8/3
SFB	5/2
EXB,SFB	8/4
SFB	5/3
EXB	8/5
SFB	3/2
EXB	8/6
SFB	5/4
EXB	8/7

Table 1: 3 stage SCC up-conversion ratios

System Design

A block diagram for the complete system and its main specifications are presented in Figure 2 and Table 2, respectively.

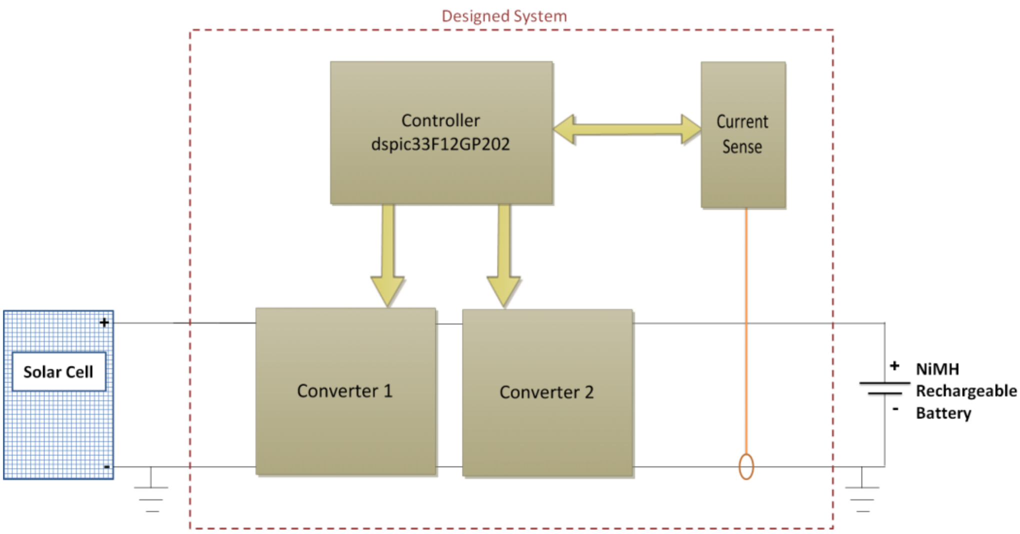

Figure 2: System block diagram

Parameter	Value
Input current	1.8-10.0[mA]
Input voltage	0.30-0.55[V]
Input power	0.75-5.00[mW]
Output current	0.25-1.50[mA]
Output voltage	2.6-3.0[V]
Output power	0.7-4.5[mW]
MPPT efficiency	97%-100%*
Conversion efficiency	85%-96%*
Total efficiency	83%-93%*
Used conversion ratio	4.5-10
Total number of conv. ratios	10

Table 2: System specifications. *based on PSIM simulations

The conversion unit contains 2 series-connected 3-stage-SCCs. This architecture is needed to achieve the required conversion ratios in terms of magnitude and diversity. The built converter is shown in Figure 3.

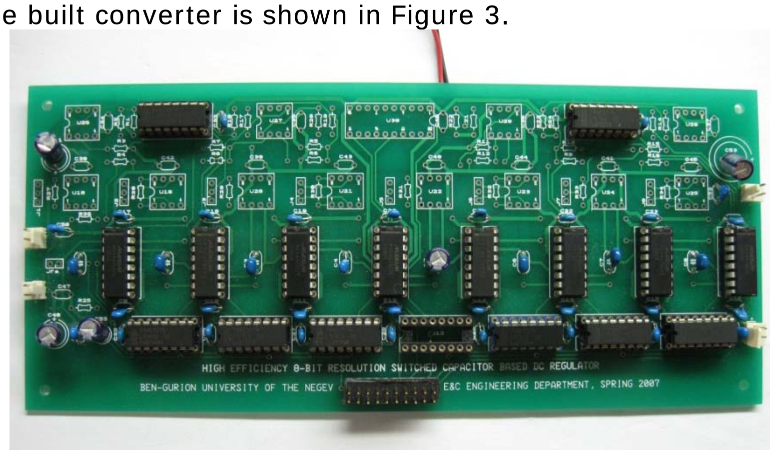

Figure 3: A picture of the SCC converter

The converter's switching control is handled by a dspic33 micro-controller. The controller is responsible for determining the conversion ratio (according to the MPPT algorithm) and for outputting the appropriate control signals of the switches.

Each conversion ratio defines a different operation point on the power characteristic curves of the solar cell and the converter output, as depicted in Figure 4.

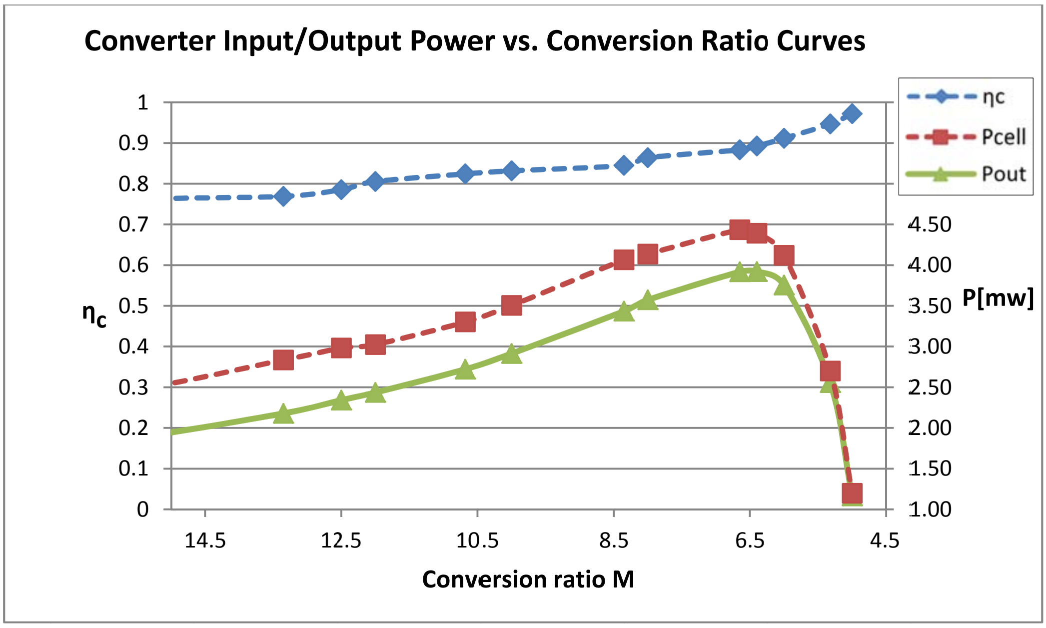

Figure 4: conversion efficiency, Pcell (Pin) and Pout curves of the system. Marked points represent the actual discrete operating points.

The MPPT algorithm is based on the Perturb&Observe (P&O) method and is responsible for maximizing the converter's output power. In this process, the conversion ratio is changed ("perturbed") and the output power is monitored ("observed") using a current sense network. As the battery voltage can be considered constant, the output current is proportional to the output power. By analyzing the current change trend, the controller can locate the system's Maximum Power Point (MPP). Figure 5 depicts typical procedures of the MPPT algorithm.

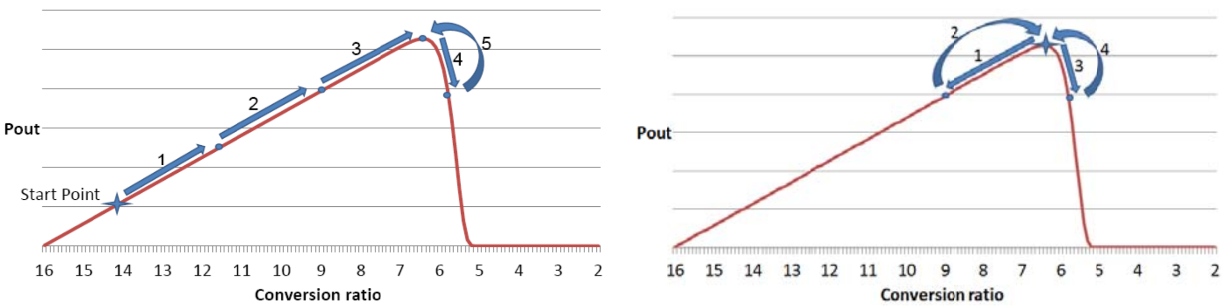

Figure 5: Typical MPPT processes (a) starting from an arbitrary point, (b) starting from the MPP

Figures 6a and 6b depict the current sense network schematic drawing and implementation, respectively. The network comprises a sense resistor set in series with the output branch and an integrator that integrates the resistor voltage. Thus, the higher the output current, the higher the integration result would be. This result is fed into the controller's A/D and then used for the MPPT.

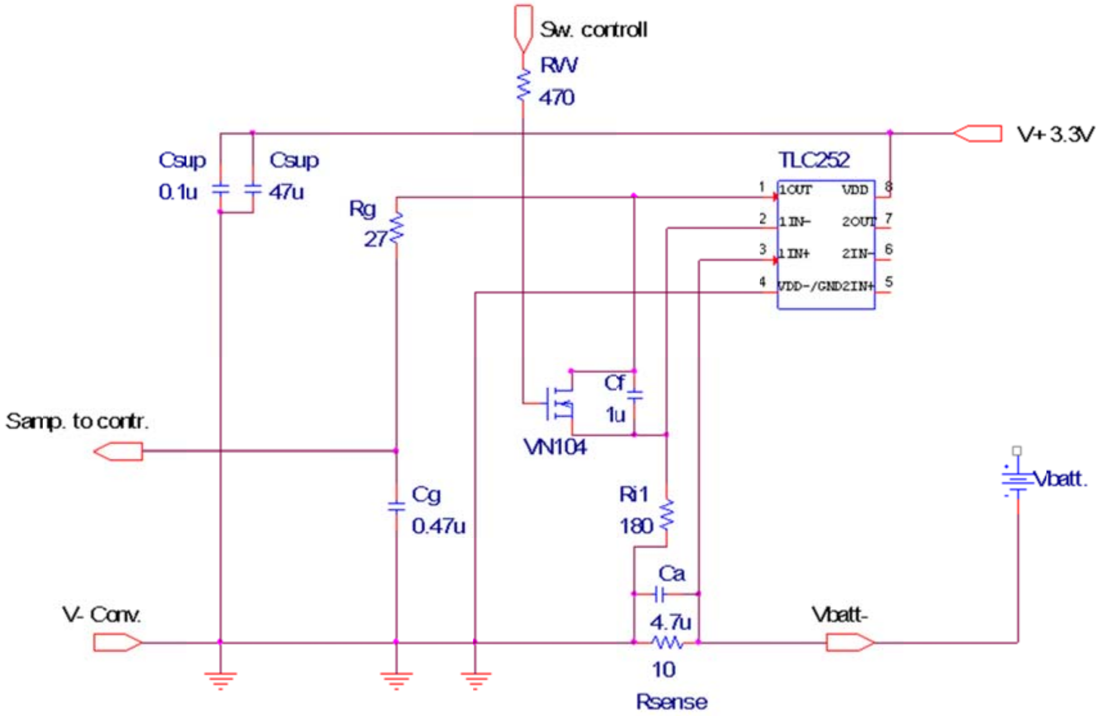

Figure 6a: Drawing of the current sense network

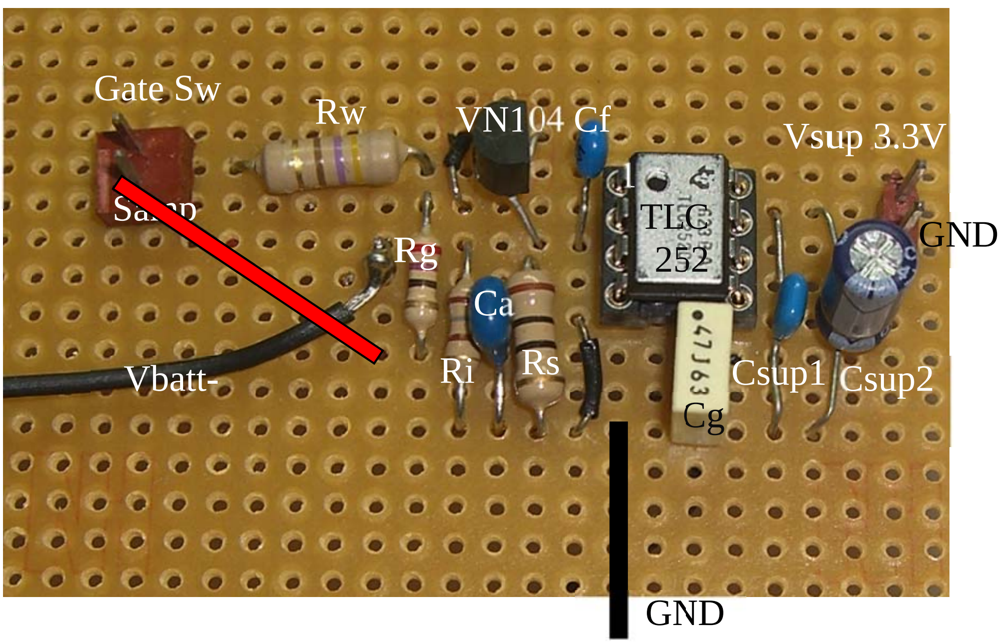

Figure 6b: Picture of the current sense network. The drawn lines are sub-board connections.

Experimental Results

The complete system was tested using solar cell and battery emulator circuits. Test results show that the voltage conversion performs as expected and that the MPPT mechanism succeeds in finding the MPP. Figure 7 depicts the voltage of the sense resistor during the MPPT process.

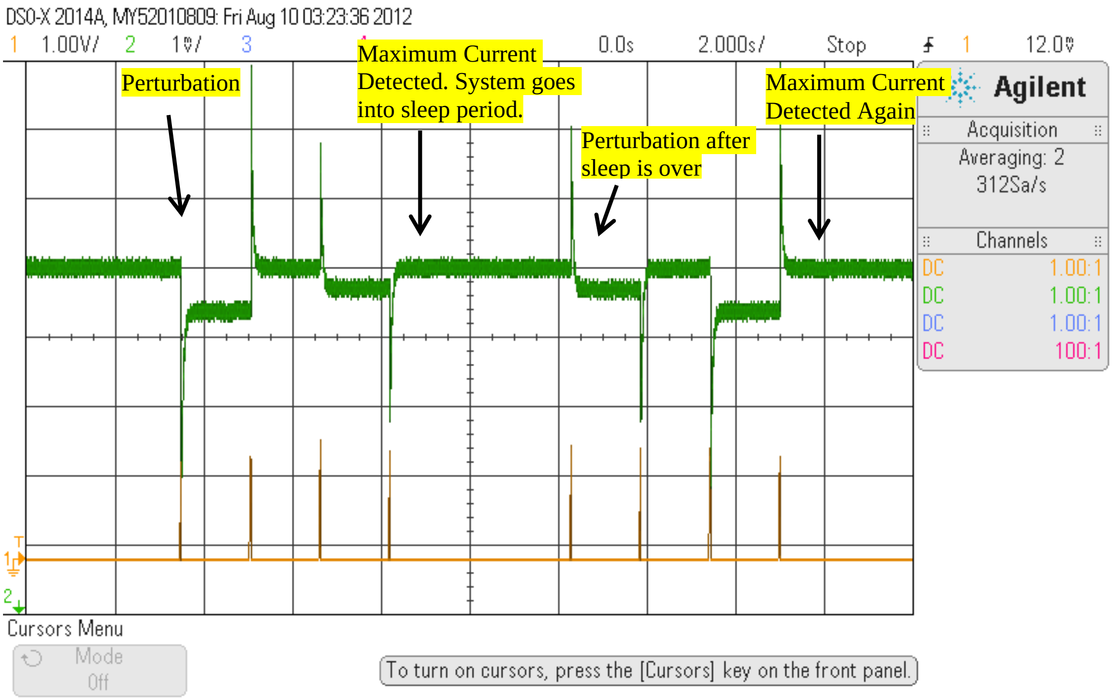

Figure 7: Averaged sense resistor voltage (green) and integration voltage (orange) during MPPT process. Note that the jumps in the resistor voltage occur *only after* the integration is over.

Figure 8 depicts the converter's input voltage during the MPPT process.

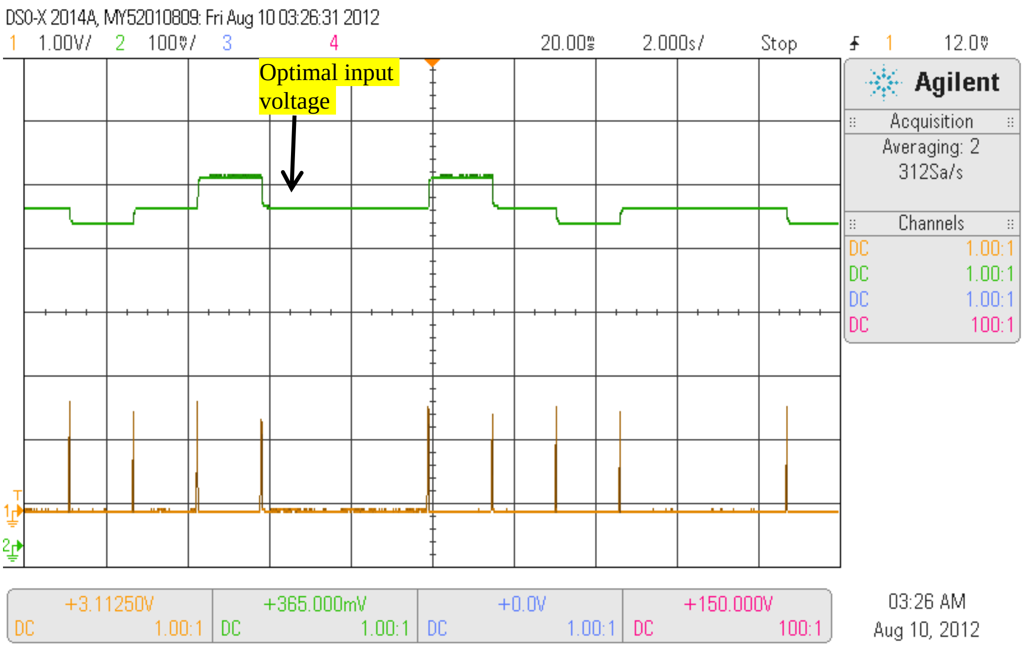

Figure 8: Averaged converter input voltage (green) and integration voltage (orange) during MPPT process

Notice that the optimal input voltage is located in between 2 other voltage levels.

The Efficiency of the system was also checked and found to be up to 65%, which is lower than the expected 85%. The results are depicted in Figure 9.

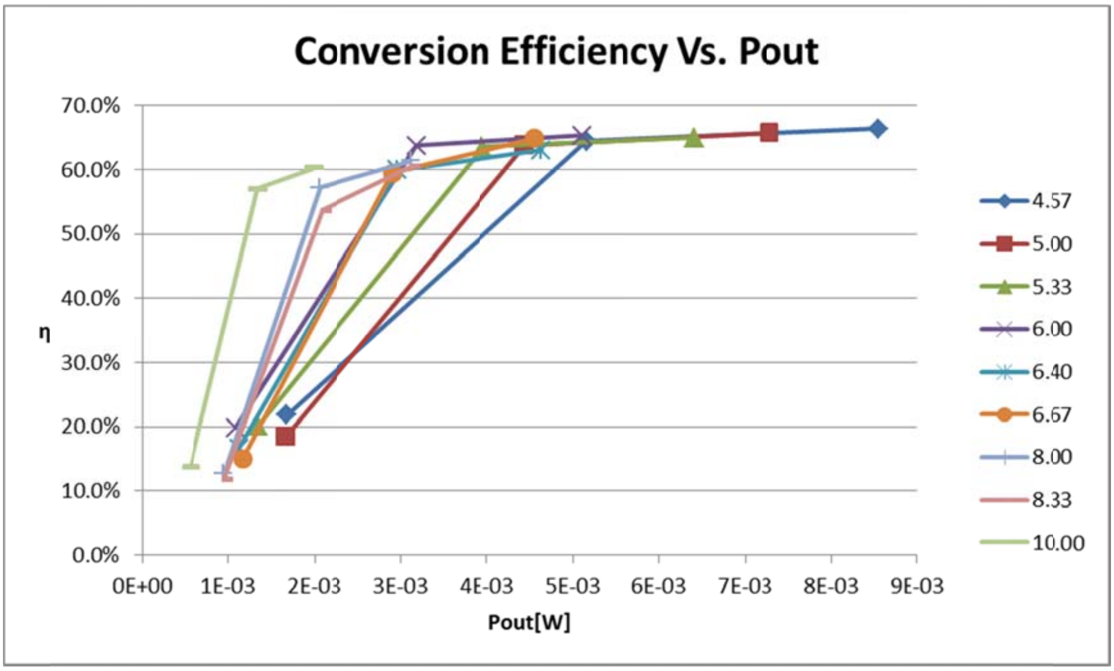

Figure 9: Conversion efficiency under test condition: V_{out}=2.8V

The low efficiency can be explained by an unexpected leakage current that was discovered during the tests. This leakage current results from inherent characteristics of the converter’s components. The appearance of this phenomenon in VLSI implementation and ways of minimizing it should be further explored.

References

[1] Kushnerov A., High-Efficiency Self-Adjusting Switched Capacitor DC-DC Converter with Binary Resolution, Thesis, Department of Electrical Engineering and Computer Science, Faculty of Engineering Sciences, Ben-Gurion University of the Negev, 2009.

[2] Ben-Yaakov, S. and Kushnerov, A., Algebraic Foundation of Self Adjusting Switched Capacitors Converters. IEEE Energy Conversion Congress and Expo, ECCE-2009, 1582-1589, San-Jose, Ca, 2009.

[3] Kushnerov A. and Ben-Yaakov S., Algebraic Synthesis of Fibonacci Switched Capacitor Converters, 2011.