Embedded software for DC/DC converter

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Introduction & Problem Statement

EnergyVille is an energy research institution located in Genk, Belgium. EnergyVille is the result of a cooperation between KU Leuven, UHasselt, VITO, and imec. The ambition of EnergyVille is to design durable and intelligent energy solutions and use this knowledge to support private stakeholders during the energy transition. One of the many fields in which EnergyVille has activities is **power electronics**.

Power electronics can broadly be defined as the application of electronics to manage and convert electrical power flows. In terms of hardware, power electronics are comprised of several electromagnetic components combined with electronic switches. These switches have to be controlled by an **embedded controller**.

There are **several challenges** in developing embedded controllers for power electronics. The learning curve is very steep and, while there is plenty of information online, it is entrenched in lengthy manuals and complicated datasheets. Furthermore, there is no predefined starting point or template for new projects.

Since creating a control system is rather time-consuming and often not relevant in the research of power electronics converters, it is desirable to reduce control software development time as much as possible. This thesis aims to facilitate this in the best manner possible.

Proposed solution

The proposed solution is threefold. Firstly, a framework was developed. This framework is a blank embedded project that provides a solid starting point for newcomers in embedded programming. The framework is comprised of three parts as shown in figure 1. The control loop section can be further subdivided into three subparts, as shown in figure 2.
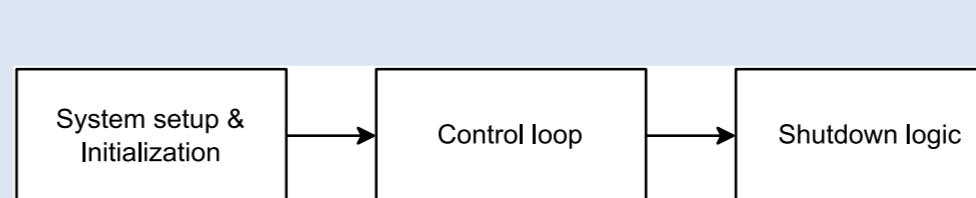

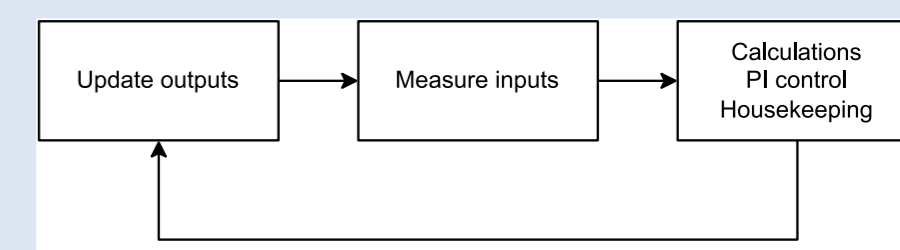
Figure 1: Framework general structure

Figure 2: Control loop subdivision

Furthermore, the framework will include a small library of utility functions. These functions aim to eliminate repetitive programming work by providing a set of functions that can be used in many cases. This includes functions to facilitate timing, PI control and hardware configuration.

Lastly, a quick start guide was written to accompany the framework and library. The purpose of this QSG is to organize the information available online and to explain the functionality of the framework.

Figure 3: Texas Instruments Delfino (TMS320f28379d) [1]

Test setup

To test the behaviour of the implemented PI controller, a small test setup was conceived and built. As the hardware itself was not the core of this thesis, using off-the-shelf parts was of importance.

A bidirectional buck-boost converter was chosen as a topology for the test setup. Figure 4 shows the schematic of this topology. Figure 5 shows the custom level shifter designed for the setup.
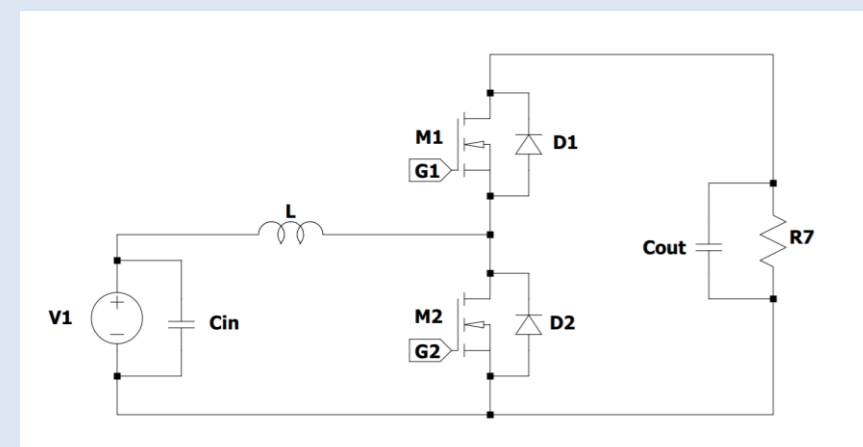

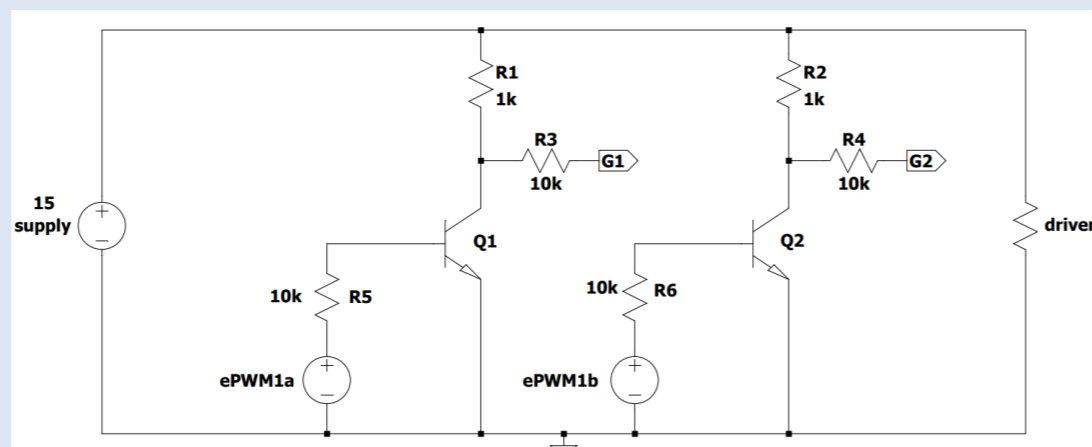Figure 4: Bidirectional buck-boost converter

Figure 5: Level shifter

Furthermore, a switching device was needed. A Semikron Semiteach was chosen due to its availability on-site, ease of use and safety. The semiteach is a 3-phase inverter with an accompanying rectifier and built-in driver designed for educational purposes. The Semiteach makes use of IGBT-style switches. Figure 6 shows the test setup. Figure 7 shows the Semiteach itself.
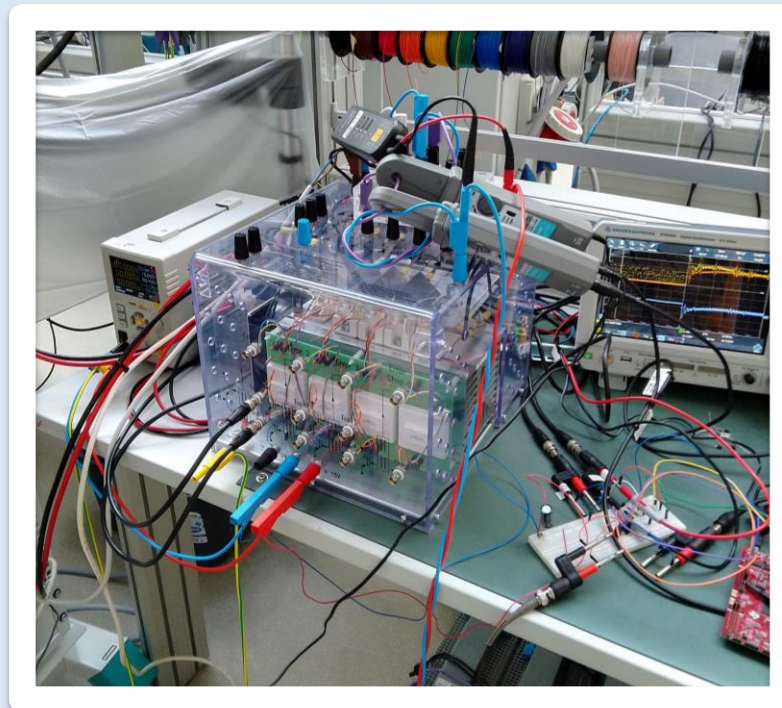

Figure 6: Test setup

Figure 7: Level shifter [2]

Results

Several different types of tests were performed. The results of a step response in current control mode, a step response in voltage control mode and step responses with varying control loop periods will be shown.
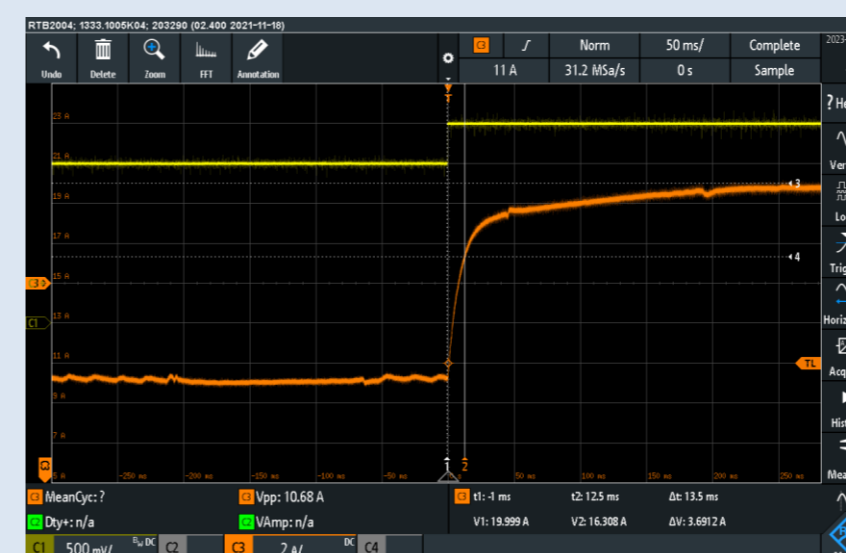
Figure 8 shows an oscilloscope screenshot of a step response in current control mode. The inductor current is in orange, while the reference step is in yellow. The step response starts at 10A and ends at 20A.

The level at which 63% of the step response has occurred is marked using the cursors (white dotted lines). A time constant of 13.5 milliseconds was achieved. Repeating the test yields similar time constants.

Figure 8: Step response in current control mode

Figure 9 shows an oscilloscope screenshot of a step response in voltage control mode. The reference and inductor current are still in yellow and orange respectively, whilst the output voltage has been added in blue.
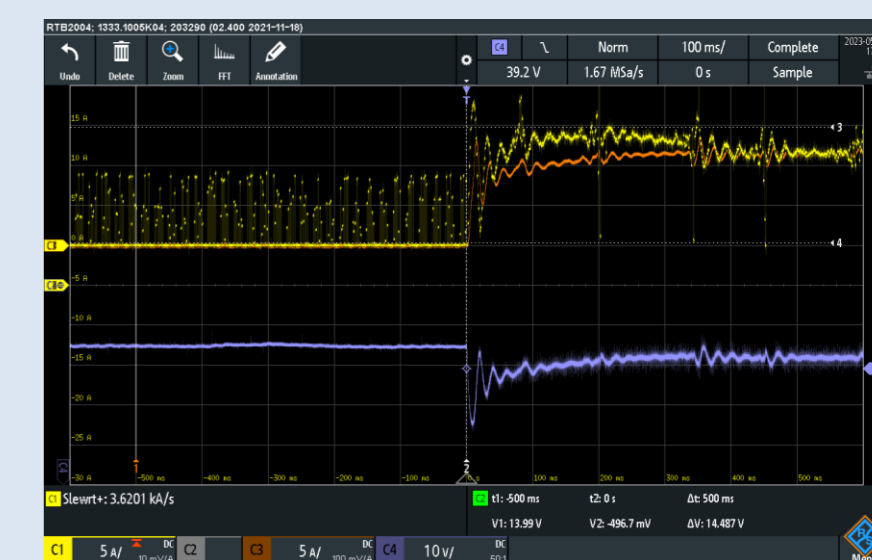
This test was conducted by suddenly adding a load to the output of the converter. This resulted in a voltage drop and a current increase as the controller tried to regulate the current to maintain the output voltage.

Figure 9: Step response in voltage control mode

Table 1 summarizes the results from the step response testing in which the control loop period was varied. This effectively results in a change in output update speed. The test started with a 1300 microsecond period and decreased by factor 10 in each consecutive test.

The resulting time constants hover around 16 milliseconds. It can be concluded that the controller update speed has no effect on system behaviour.

Table 1: Step response with varying control loop period results

Symbol	Result 1	Result 2	Result 3	Result 4
$t_{control\ loop}$	1300 μs	130 μs	13 μs	1.3 μs
τ	17 ms	15 ms	15 ms	16 ms

[1] Mouser Electronics. (n.d.). *Texas Instruments TMDSDOCK28379D F28379D Delfino Experimenter Kit*. Retrieved June 3, 2023, from https://www.mouser.be/new/texas-instruments/ti-tmdsdock28379d-experimenter-kit/?_gl=1*b7qe27*_ga*dW5kZWZpbmVk*_ga_15W4STQT4T*dW5kZWZpbmVk*_ga_1KQLCYKRX3*dW5kZWZpbmVk

[2] SEMIKRON, 'Semiteach IGBT', Sep. 01, 2015. https://www.thierry-lequeu.fr/data/SEMITEACH-IGBT-datasheet-2019.pdf (accessed Apr. 20, 2023).

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