State of the Art PE Control Solutions Development

The development and validation of control algorithms in record time

Since 1991 Končar Electrical Engineering Institute (KEEI) Inc. has been involved in development and delivery of embedded power electronics controls solutions to companies within KONČAR Group and for the open market.

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The Project
KEEI was asked to develop an embedded control solution for scalable/modular 150kW, 400V, 50Hz three-phase, single-stage central photovoltaic (PV) converters. The specifications required a state of the art solution, fully developed and tested within six months.

The Challenge
Development and implementation of a robust fully tested control system that would ensure optimal control of active and reactive power, maximum power-point tracking, fault ride-through and anti islanding functionalities.

Usually, KEEI's teams follow the standard sequence of development steps for power electronic control solutions:

1) analysis of requirements, related norms and in-house knowledge and experience
2) development of a switching model of the power hardware with an off-line simulation package for system analysis at switching frequency time scales
3) development of a linear model (in millisecond or longer time scales)
4) simulation and verification of the performance of the proposed converter topology, typically using various software tools (due to software limitations, component model complexity and other issues).
5) synthesis and testing of control algorithms using different simulation tools depending on the observed time scale and other requirements
6) iteration of the previous steps until the required converter behavior is achieved,
7) preparation of production documentation for embedded control system
8) conversion of control algorithms developed by means of simulation software to real time application program of the target embedded control system
9) building of the prototype embedded control system
10) verification of a complete control system and debugging of implemented control algorithms on a prototype controller platform
11) qualification of the complex system
12) building, testing, validation, delivery and commissioning.

Typically, most of the time allocated to a project is spent on Steps 2 to 6 as one major group and later on Steps 7 to 9, i.e. in waiting for completion of the prototype converter and its associated embedded control system.

The Solution
For the purposes of this project, due to a tight development timeframe, a different approach was tested. For the first time, KEEI's team used a Hardware-in-the-Loop emulator system, a Typhoon HIL600, which is able to model power electronic converters as well as associated passive components.

With the emulator system, we managed to drastically shorten the time needed for Steps 2 to 10. On the Hardware-in-the-Loop emulators, a model of a PV converter with all the passive and active components was realized, which particularly shortened steps 2 to 4.

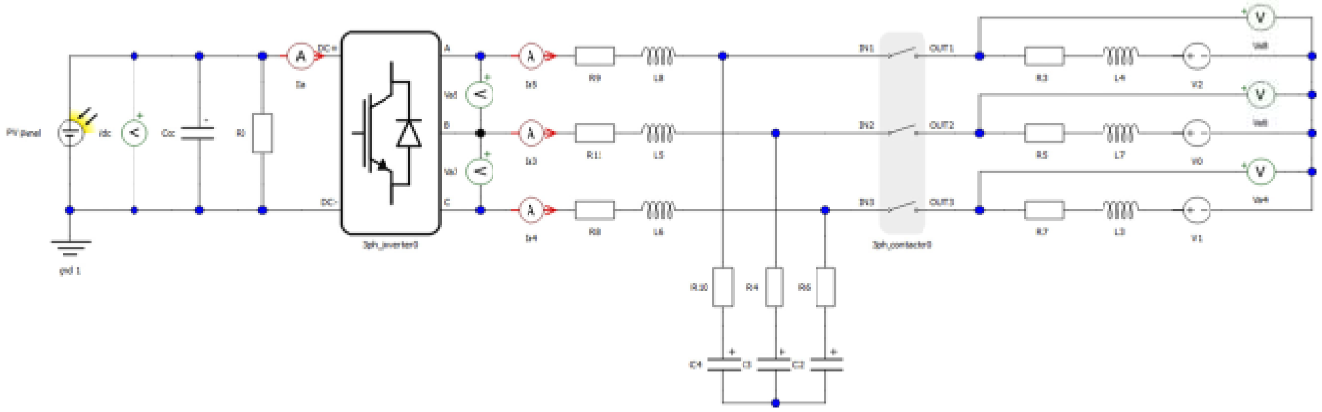

Figure 1: The configuration of the central photovoltaic inverter

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Implementation of the control algorithms and automated testing procedures could now start on a rapid prototyping platform which comprised the aforementioned emulator and a proprietary TI docking station, with a Texas Instruments TMS28335 control card. Instead of using the usual textual programming of the control algorithms within the TMS28335, we adapted and used our proprietary Graphical Programming Integrated Development Environment GRAP IDE. Within KONCAR, this software tool is used for the development of power electronics and other special control solutions. The combination of our GRAP IDE and Typhoon HIL600 helped us to simultaneously develop and test all aspects of the control algorithms directly in the target DSP, which saved many time-consuming simulate?implement?test sequences. The result was a fully tested control algorithm implementation before production of the embedded control system was finished. Thus, it was possible to influence changes in the hardware concept of the embedded control system prior to release of the first version of production documentation.

Figure 2: Proprietary graphical programming integrated development environment GRAP IDE

For example, the filtering requirements (slope and bandwidth) on analog inputs could be corrected and additional error-signaling and temperature probe inputs implemented.

The next steps were functional tests of the produced embedded control system. Rather than waiting for the converter to be assembled, this step was also performed on the Typhoon HIL600 which was now connected to the produced control system via a custom interface.

With such a rapid prototyping platform it was easy to repetitively test conditions that could be prohibitively expensive or impossible to test in the laboratory. These conditions include sudden changes in insolation (due to cloud-cover), PV panel dropout, extreme harmonic pollution, grid faults and so on. Those complicated and sometimes dangerous tests were performed in the safety of an office with the help of this emulator. All changes in the application program were implemented on-line with no concerns about expensive component failure. PID controller tuning is a good example. Our developers could change PID controller parameters by several orders of magnitude. For instance, time constants could be changed from microseconds to several milliseconds to check system stability (and to purposely push it to oscillation limits) with no concern about the hardware. The effects of the modifications were visible instantly which allowed the complete testing and debugging of the control system before applying it to the PE converter.

Figure 3: The delivered control system in cabinet of developed PV converter

An important parameter that was clearly seen and could be easily assessed by using GRAP IDE on the rapid prototyping platform (instead of the simulation tools) was the influence of different “correct” PWM frequencies (which lead to symmetric PWM signal generation) such as 3.6kHz or 2.4kHz and “odd” frequencies such as 2.6kHz, on the generated harmonics and stability of the complete control system.
A lot of troubleshooting was done using the rapid prototyping platform. Some abnormal and non-consistent harmonic components were tracked down to the faulty order of execution of program blocks. Several ill-defined program blocks were found during the automated testing (a problem that could stay dormant for months if a system were immediately deployed in a converter) and program cycle times were adjusted according to the test results. In addition to that, we were able to optimize the program by slowing down the operation of program blocks, which were found to be non-crucial, from microsecond to millisecond time ranges. Furthermore, some high performance digital filters (that were using a lot of processing time) were, after the testing in the hardware-in-the-loop, transferred to the control system FPGA component.

Results

The development of the embedded control solution for the central PV converter was completed in only five months and with only four full-time developers. The control system has successfully met all the applicable standards and proved to be a robust and reliable system. The PV converter, as a result, showed great performance on the EN50530 defined tests and was able to fulfill national grid code requirements.

Conclusions

By using the described HIL-GRAP rapid prototyping platform, our team could directly implement their ideas and no time was spent on iterative and time-consuming simulations. For example, complete variable time step simulation of the converter and control system took about 4 hours per second of converter operation versus real-time operation on the rapid prototyping platform. Many errors connected with the simulation tools themselves, e.g. adjusting time-step range and computing precision were bypassed altogether.
Finally, cumbersome hardware configurations and costly laboratory testing were cut down considerably: there was no need for disconnection of converter components to fit the precision current transducers required for grid compliance measurements and moreover, our developers could work in a completely safe environment – there were no PV field-related high DC currents (of up to 400A) and voltages (of up to 1000V). As a consequence our time-to-market was the shortest ever!

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