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Open HW/SW Platform Accelerates Development Of Control Solutions For Power Electronics

by Marko Vekic, Vlado Porobić and Evgenije Adzic, PERUN Technologies, Novi Sad, Serbia

The process of developing a controller at the power electronics (PE) or power systems (PS) level requires a great deal of versatility and expertise in various engineering areas. This is especially true for many large, high-power applications such as motor drives, active filters, photovoltaic inverters, and flexible ac transmission systems (FACTS). Controller development is very time-consuming, laborious and expensive and yet very inflexible if a traditional testbench approach is applied. Typical existing equipment includes only one type of tested hardware and a controller. The resulting test setup is therefore inflexible and severely limited to one specific application, where all further modifications, even small ones, are expensive, primarily in terms of invested time.

Three main challenges are usually faced in the whole process:

1. Building or modifying the power stage (hardware) is usually a very time-demanding and non-scalable process.

2. Connection of a controller platform that is to be developed takes a significant amount of time to solve issues that arise in interfacing the power stage with the controller. Moreover, all future modifications demand extra effort.

3. Development and testing of control code is based on a low-level programming language.

The tasks listed above pose a challenge even for experienced engineers, especially when strict development deadlines are in place. These are even more challenging for inexperienced engineers, PhD researchers and students. A high investment is required to provide all the equipment necessary for thorough and versatile PE research or education. Simply put, a great deal of equipment is needed if researchers or students are to perform a wide range of necessary experiments. In spite of all these difficulties, we must keep in mind that experimentation is essential and an irreplaceable step in building, testing and verifying a user's power electronics or power systems controller design.

To cope with these three challenges, PERUN Technologies has developed a comprehensive open platform which includes both hardware (HW) (i.e. power stage and interfaces) and software (SW) components. This platform serves as a "Launch Ramp" for development of controllers for power electronics and power systems and from that description the name of the product—the LARA-100—is derived.

After describing the key features of the LARA-100, this article explains how this platform can be used in three different ways: for controller development in the first scenario; to supplement an existing development platform (with LARA-100 emulating a source or load) in the second scenario or as a combination of these uses. Then, two case studies are presented to illustrate the first two use scenarios. In the first case study, which illustrates controller development, the LARA-100 is configured as a STATCOM that provides reactive power injection to a power grid. In the second case study, the LARA-100 is configured as a motor load.

Platform Design Objectives

The LARA-100 is designed to solve the above mentioned issues that designers face when developing a controller. First, the LARA-100 replaces the standard laboratory testbench and its need for exhausting modifications with a platform that can be configured to stand for a variety of applications—motor drives, active filters, PV converters, and FACTS, as well as to support some larger research projects such as micro-grids and smart grids.

Second, the interface with popular control platforms, such as Texas Instruments' C2000 series is provided. And finally, the user's control algorithm is tested directly from an intuitive software suite called PERUN Power Desk

(PPD) which enables embedded oscilloscope functionality and online access to all variables that the user defines in a controller. PPD also offers on-the-fly signal analysis, mathematical operations between signals and control design tools.

The reconfigurable nature of the LARA-100 allows various experiments to be performed on a single piece of equipment, thereby reducing the effort, cost and space for infrastructure. The idea behind LARA-100 is very simple and it can be summarized as follows (Fig. 1): let us take one standard, commercially available power electronics converter and transform it into the open and flexible platform for PE and PS control development. How is this goal accomplished?

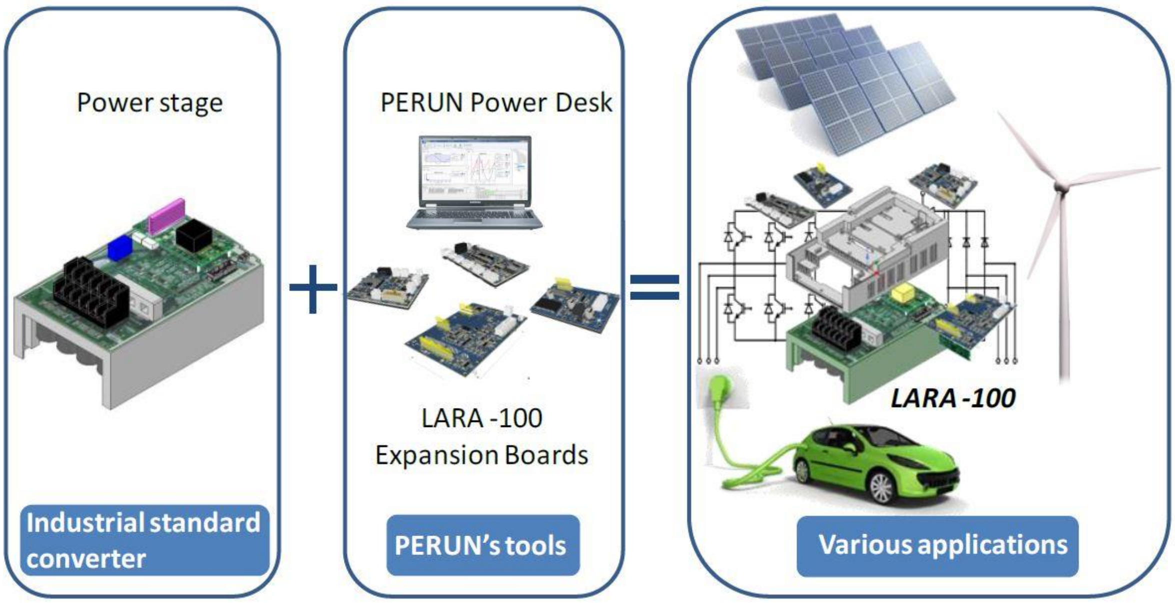

Fig. 1. The key concept behind the LARA-100 is the ability to reconfigure this open platform to represent the user's specific application. Typical applications include motor drives, photovoltaic inverters and microgrids.

Simply put, we employ the industrial converter's power stage and combine it with LARA's expansion boards. The role of these expansion boards together with the PERUN Power-Desk software suite is crucial in the creation of the LARA-100 as an open and configurable platform. These boards enable interfacing with popular controllers such as Texas Instruments' C2000, but they also expand the scope of LARA's possible applications (motor drives, renewables, automotive designs) and enable communication with a variety of external devices such as encoders, resolvers, PLCs, other LARAs, etc. through CAN, USB, Ethernet, JTAG and RS-485 buses.

The LARA-100 Motherboard is the main hardware component in the system and works together with the LARA-100 expansion boards to dramatically expand the applicability of the overall LARA solution. The expansion boards include the Application, Communication and GPIO boards. The user's controller (a TMS C2000 series DSP, for example) is interfaced to the LARA platform through the LARA Motherboard (Fig. 2). LARA's software suite, the PERUN Power Desk, is responsible for system configuration, supervisory control, data acquisition, manipulation and analysis.

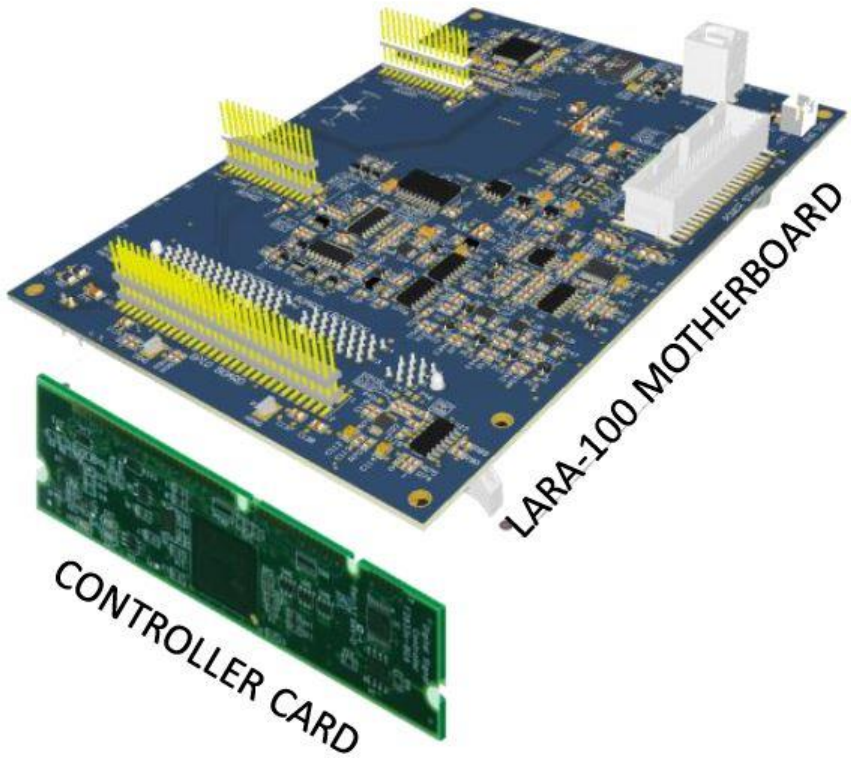

Fig. 2. The LARA-100 Motherboard with a plug-in TMS320F28335 DSP.

Reconfigurable Power Stage

There are two key features that make LARA's power stage configurable. First, by providing access to all relevant power nodes in the power stage (ac mains, dc link, and ac load or source) the LARA-100 can be utilized in a variety of applications, such as single-phase or three-phase motor drives (induction machine, PMSM), grid-connected converter (STATCOM, active filters, active front end converter, etc.) as well as dc applications such as photovoltaic (PV) boost converter or separately excited dc motor drive. In this way, one LARA-100 unit or several LARA-100 units are configured to represent the application of interest by means of topology.

Second, each building block can be configured within the power range of 0.25 kVA to over 100 kVA while the dc bus voltage can be set in the range of 24 V to 800 V by means of the PERUN Power Desk in terms of the software and the LARA-100 Motherboard in terms of the hardware.

The LARA Motherboard offset calibration is performed automatically with configurable gain settings to obtain full-scale measurements. All measurement signals are automatically scaled to the full analog input range of the microcontroller (0 to 3 V) to maintain the highest conversion resolution. Gain settings are configured through digital potentiometers by means of the PERUN Power Desk software suite.

Measurement circuit design provides low gain error below 1% and low linearity error below 0.3%. For instance, the measurement gain could be selected in such a way that overload current, which is 2.5 times higher than the nominal value, produces a voltage between 0 and 3 V at the controller's analog input, i.e. numerical values between 0 and 1 p.u. after ADC conversion.

The LARA-100 contains protection circuitry necessary for reliable protection of both the LARA-100 itself and for the protection of the connected load or power source. Programmable trigger levels for output line overcurrent and dc bus under/overvoltage adapt the system to specific needs.

Extending The Application Range

Expansion boards support the overall LARA-100 configurability and flexibility, enabling connection with encoder and resolver signals, grid measurements, PLCs, peripheral devices, SCADA, etc. In this way, the LARA-100 is configured to support a variety of applications. As mentioned before, aside from the LARA-100 Motherboard, there are three types of expansion boards: Application boards, General Purpose I/O (GPIO) boards and Communication boards.

Application boards allow interfacing the controller with various sensors such as incremental/absolute encoders, resolvers, tachogenerators, grid-voltages probes or other devices. Application boards support different signal voltage levels, dependent on the user requirements. Consequently, the LARA-100 can be configured to achieve a variety of power electronics applications.

GPIO boards allow interfacing with different digital/analog signals between the user and controller. All digital and analog inputs and outputs are galvanically isolated. Digital outputs can be of the relay or optical type. One digital output is reserved for signaling system error. Digital inputs can also be of various logic levels: 5, 15, or 24 V or optical. One digital input is reserved for manual error triggering. In an analog signal interface section, voltage/current transducers are used when interface cables are too long for proper measurement.

Communication boards connect the LARA-100 to Ethernet, CAN bus, RS-485, RS-232, JTAG and other networks.

Software Components

PERUN PowerDesk (PPD) is a set of software components enabling supervisory control, data acquisition, signal analysis, and control design in the framework of the LARA-100 development system. It provides a structured, project-based work environment. There are three distinctive PPD features (Fig. 3)—Oscilloscope function, Tag explorer and Signal analysis tools.

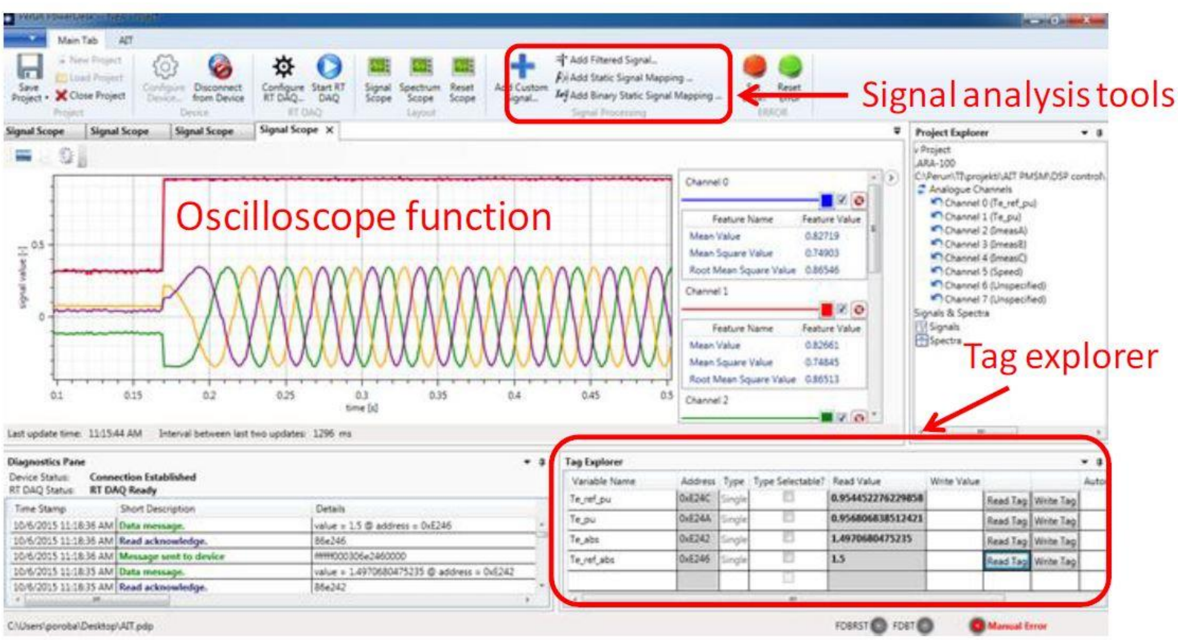

Fig. 3. PERUN Power Desk features: Oscilloscope function, Tag explorer and Signal analysis tools.

The Oscilloscope function is responsible for displaying signals available in the controller. Tag explorer is a very convenient tool that enables online access (reading and writing) of all used variables. This means that the user can perform online modifications of different control parameters, for instance to change PI controller gains and observe the immediate response using the Oscilloscope function. Obtained results (measured and calculated) can be analyzed using Signal analysis tools (Bode plot, Fourier analysis).

All of the mentioned functions and tools combine to create an extremely powerful environment for controller development, debugging and testing. Beside those already mentioned, there is one very useful tool for mathematical manipulation of measured signals. For instance, instant power can be calculated and displayed based on measured currents and voltages in real time directly from the PPD environment rather than coding it in a controller. PERUN Power Desk also serves as the tool for supervisory control of the LARA-100's overall operation (start/stop functions, defining measurement gains, protection functionality, etc.)

It is important to emphasize that while the PERUN Power Desk can be used as a component of the LARA-100 overall system, it can also be used as a standalone environment for development and debugging of Texas Instruments' C2000 DSPs (for arbitrary DSP control applications). In such a scenario, PPD with its embedded oscilloscope function, direct access to any DSP variable "on fly" including mathematical manipulations of measured signals and signal analysis tools can be employed as an extremely helpful and convenient extension of TI's Code Composer Studio.

Application Examples

The LARA-100 can be used in one of three ways—as an open platform for controller development, to supplement an existing development/testing platform, or some combination of the two.

Platform For Controller Development

In this first scenario, the aim would be to develop a controller, for example, a motor drive controller or a grid-connected application controller such as an active filter, wind-turbine power converter or photovoltaic inverter. Three principal pieces are generally needed: a power stage, a controller and an interface between the first two. To develop the control code itself, a user needs to use some programming language.

Now, in order to avoid building a new laboratory testbench or modifying an existing one, the LARA-100 can be easily reconfigured via PERUN Power Desk and expansion boards to support different desired applications. In such a way the assumed effort in building and nursing the testbench is minimized or completely eliminated. Combining expansion boards with the power stage (Fig. 1 again) and performing software configuration (Fig. 3 again), a user can reconfigure the same LARA-100 system again and again according to specific project needs. In this scenario, the LARA-100 is the platform that the user employs and configures to test the control algorithm of interest.

Furthermore, keeping in mind that programming the control code in C-language might be time consuming, especially for inexperienced engineers, PERUN Power Desk supports so-called "autocoding functionality." This means that the control algorithm can be designed directly from Simulink and automatically compiled and downloaded to the controller. In this way, rapid control prototyping is achieved. Testing and debugging goes easier because PERUN Power Desk includes the embedded oscilloscope and control design tools, which make the development loop (test-modify-test) very short.

Supplementing A Development/Testing Platform

In this scenario, a user is satisfied with the existing laboratory testbench, but needs to supplement it with an additional important element such as a grid emulator, PV emulator, programmable motor load, etc. The LARA-100 can be employed as the base of the mentioned devices. A user can employ this strong configurable base to build the desired equipment or the PERUN team can perform customizations if needed.

In this case, the role of the LARA-100 can be described as a "black-box" with the objective of operating as the desired equipment (grid or PV emulator, motor load, electronic load, etc) while the user develops a control algorithm in another LARA or third-party system.

Combinations

Finally, the first and second scenarios can be combined. For example, a new control algorithm for a PV application needs to be developed and tested. In this case, one or more LARA-100s can be configured to build the PV system and develop the controller. However, if the user doesn't want to use real PV panels, the LARA-100 can be the base of the device that emulates PV panel operation. This proves to be more convenient than connecting to actual panels stationed on a roof or outside of the laboratory in general.

Another example would be a motor drive. The LARA-100 could be used as the platform that drives the motor in accordance with the user's control algorithm under development in Texas Instruments' C2000 series DSP. Now, in order to load the motor and test the whole drive, another LARA-100 could be employed to drive the dynamo machine coupled to the motor under the test.

In order to illustrate the first and second scenarios, two simple case studies will be presented—one with the LARA-100 configured as a STATCOM (the first scenario) and the aforementioned case where the LARA-100 is the base of a dynamo drive (motor load).

Case Study 1: LARA-100 Configured As A STATCOM

In this very simple, but illustrative example, the user configures the LARA-100 in the form of a STATCOM (Fig. 4) that injects reactive power into the power grid. Configuration of a STATCOM is easily performed in a few steps: connecting appropriate power stage nodes to the grid-coupling elements (transformer and inductances) and completing system configuration through the PERUN Power Desk software suite.

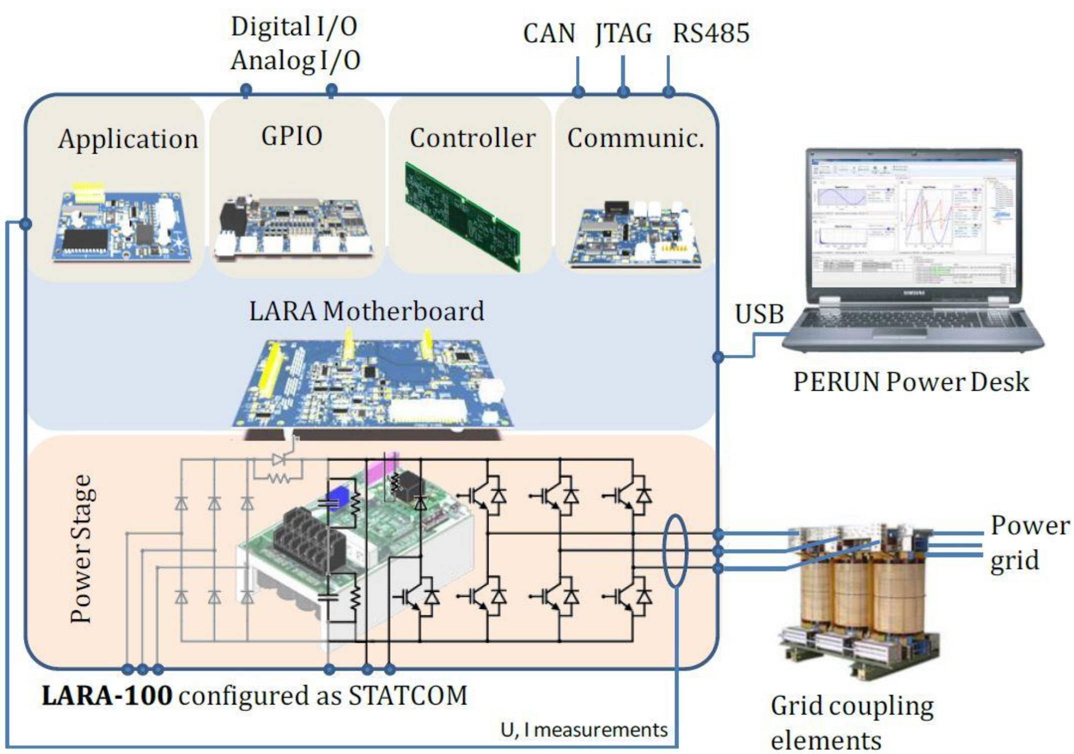

Fig. 4. The LARA-100 configured as a STATCOM.

Voltages and currents are measured through an Application board, which is directly connected to the power stage measurement probes via LARA's Motherboard. A Communication board enables CAN, JTAG, RS-485, RS-232 and Ethernet communication.

A CAN bus could be used for connection with an external, high-level supervisory controller and/or for communication with other LARAs. JTAG is very suitable for low-level controller coding (current loops, dc link voltage control etc.) Meanwhile, a GPIO board provides analog and digital I/O. Here, digital outputs are employed for signaling (errors, power supply indication) and controlling contactors (dc link capacitors pre-charging and connection to the grid).

Experimental results obtained from a LARA-100 configured to operate as a STATCOM are provided in Figs. 5 through 9. PERUN Power Desk tools such as Oscilloscope function and Signal analysis Desk are used for the code testing and debugging of the controller (a TMS320F28335 here).

Another extremely useful feature, Tag explorer is employed to access any variable conceived in the controller code. We will demonstrate here its functionality by changing the STATCOM's reactive power reference, but also by modifying proportional and integral gains of the STATCOM's current regulator, which controls phase currents. It is very important to note that these parameters are modified online without the need for stopping the system operation and running it again.

To test the STATCOM control algorithm, the response to a reactive power step reference will be analyzed (Fig. 5.) The step reference's initial value is 2000 VAr, while the final value is set to 13000 VAr.

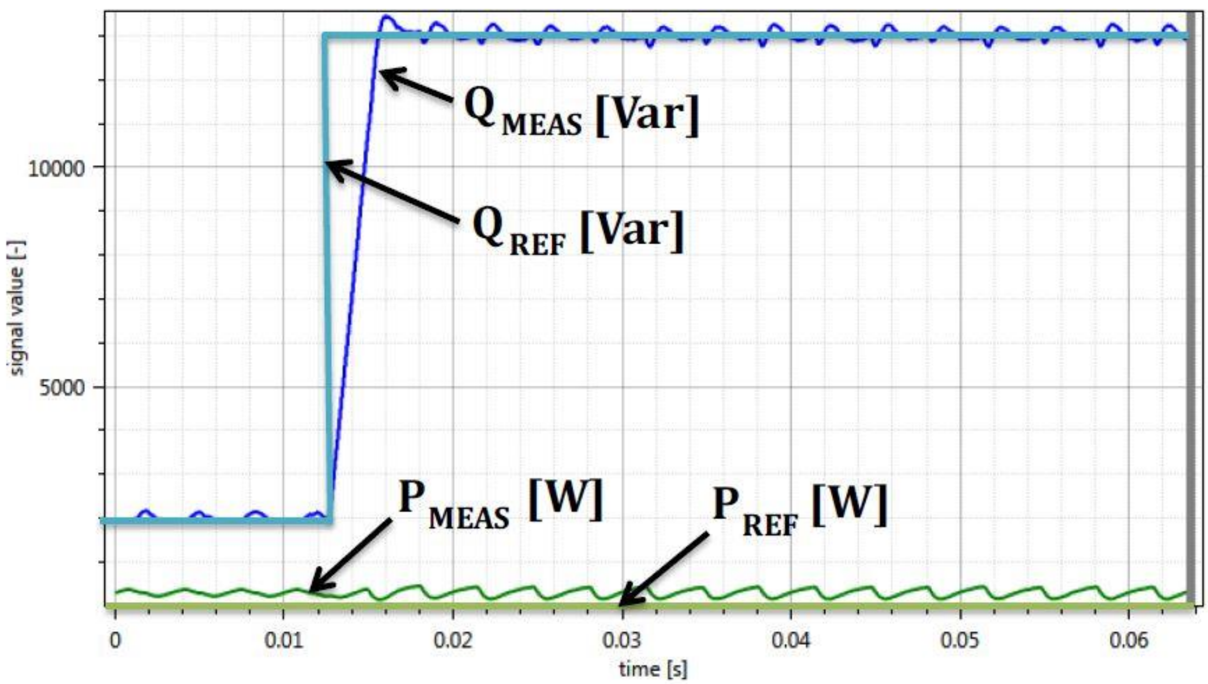

Fig. 5. STATCOM response to step change in reactive power from 2 kVAr to 13 kVAr.

It can be noted that the rise from Q_{REF} = 2000 VAr to Q_{REF} = 13000 VAr is obtained in about 6 ms. Active power reference P_{REF} is set to zero. However, the measured active power is about 200 W. This discrepancy is a consequence of the converter's losses.

Let us analyze the current waveforms for both cases (Q_{REF} = 2000 VAr and Q_{REF} = 13000 VAr). In Fig. 6 the results are presented for the case when Q_{REF} = 2000 VAr. From the waveform of the measured current I_a and its spectrum it is obvious that there is a sixth harmonic present.

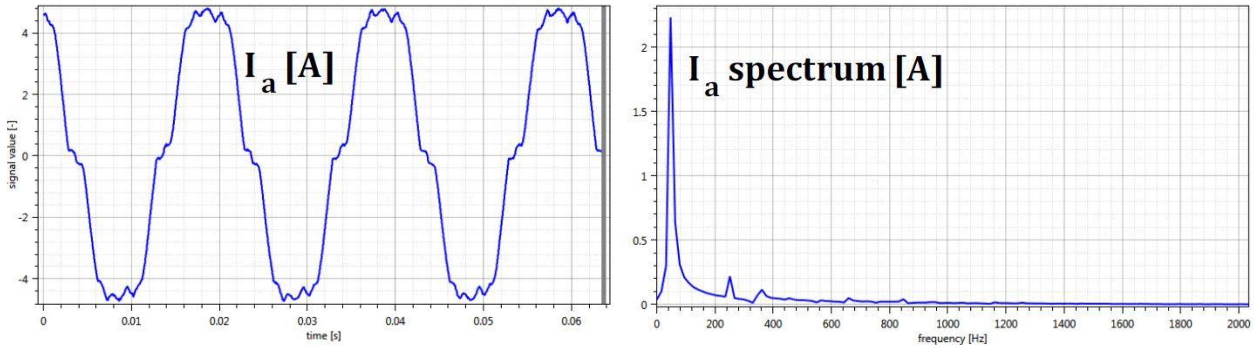

Fig. 6. STATCOM phase a current waveform and its spectrum for Q_{REF} = 2000 VAr.

This harmonic can be explained by LARA's power stage deadtime of 3.2 µs, which produces "deformations" in the voltage waveform six times per cycle, hence the sixth harmonic in the spectrum.

Let us analyze further the situation where Q_{REF} = 13000 VAr (Fig. 7). In this case it can be clearly noticed that the current waveform is cleaner than in the previous situation. This is understandable since the reference reactive power and hence current magnitude is several times higher, which means that the effect of the deadtime is proportionally smaller.

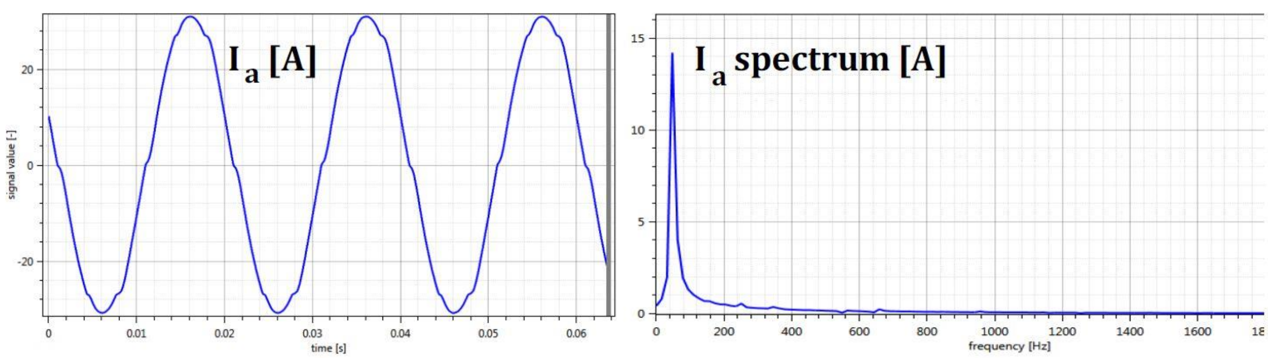

Fig. 7. STATCOM phase a current waveform and its spectrum for Q_{REF} = 13000 VAr.

Finally, to demonstrate the LARA-100's potential in rapid control prototyping we will significantly decrease (by five times) the PI controller parameters using *Tag explorer* (Fig. 8) and immediately observe the real-time response via the Oscilloscope function.

Tag Explorer

Primary Device

Variable Name	Address	Type	Type Selectable?	Read Value	Write Value			Automatic Write?	Read Only?
User_Pref	0xE2A4	Single	☑	**0**		Read Tag	Write Tag	☐	☐
User_Qref	0xE2AA	Single	☑	**13000**	13000	Read Tag	Write Tag	☐	☐
pid_curr_d.Kp	0xE4DE	Single	☑	**0.0799999982118607**	0.08	Read Tag	Write Tag	☐	☐
pid_curr_d.Ki	0xE4E0	Single	☑	**0.00300000002607703**	0.003	Read Tag	Write Tag	☐	☐
pid_curr_q.Kp	0xE49E	Single	☑	**0.0799999982118607**	0.08	Read Tag	Write Tag	☐	☐
pid_curr_q.Ki	0xE4A0	Single	☑	**0.00300000002607703**	0.003	Read Tag	Write Tag	☐	☐
			☐					☐	☐

Fig. 8. Modifying PI controller gains "online" directly from PPD software suite.

In the same diagram (Fig. 9) the response will be compared with the old one from Fig. 5.

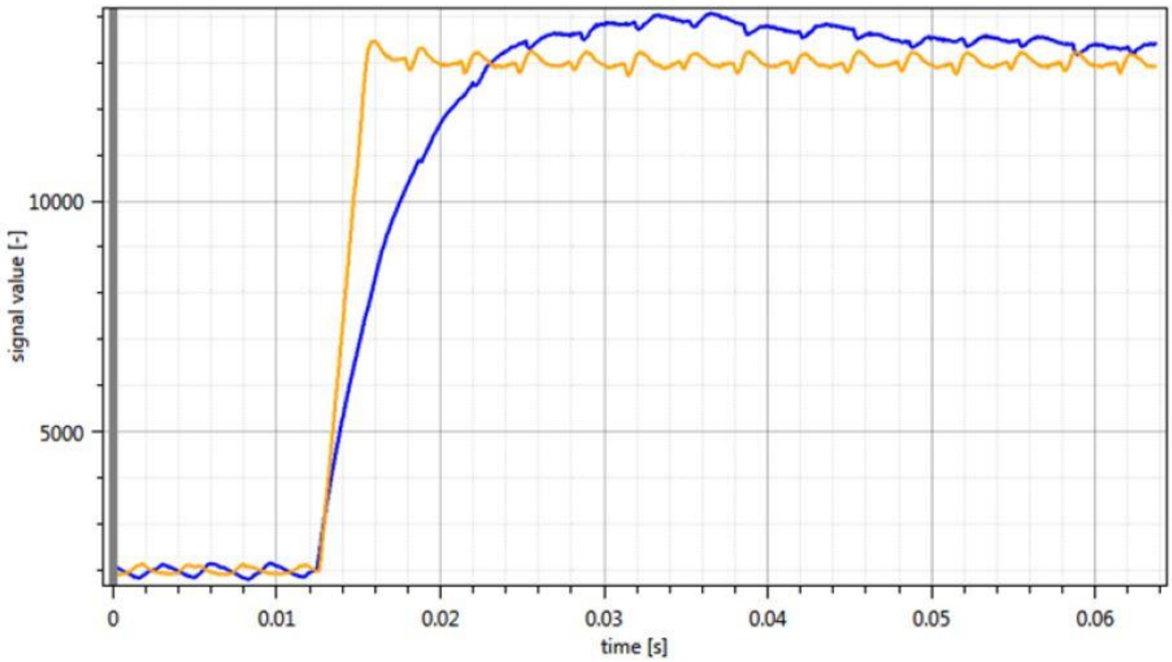

Fig. 9. Responses to a step change in the reactive power reference for different PI controller gains.

The response with the old parameters is shown by the orange trace, while the STATCOM response with decreased PI controller gains is shown in blue. Obviously by decreasing the PI parameters, the response is significantly slowed down, as expected.

The described case study has demonstrated several important points. One is the simplicity of configuring the LARA-100 to operate as a STATCOM. Another is PERUN Power Desk's significant capabilities in testing and debugging of the user's controller through Tag Explorer, Oscilloscope function and Signal analysis desk among others. It also demonstrates that all those tasks can performed in a safe hardware platform.

The next example will illustrate another important LARA-100 capability. This is the platform's ability to be reconfigured to act as a specialized source or load such as a motor load (dynamo drive.)

Case Study 2: LARA-100 Configured As A Motor Load

In this case, the user employs a LARA-100 configured as motor load (dynamo drive, Fig. 10.) This means that the user doesn't change LARA's control algorithm (although this could be easily done), but the focus is on the testing of the user's external converter and its controller. Therefore, the LARA-100 can be imagined here as a "black box" that produces the desired load profiles i.e. torque.

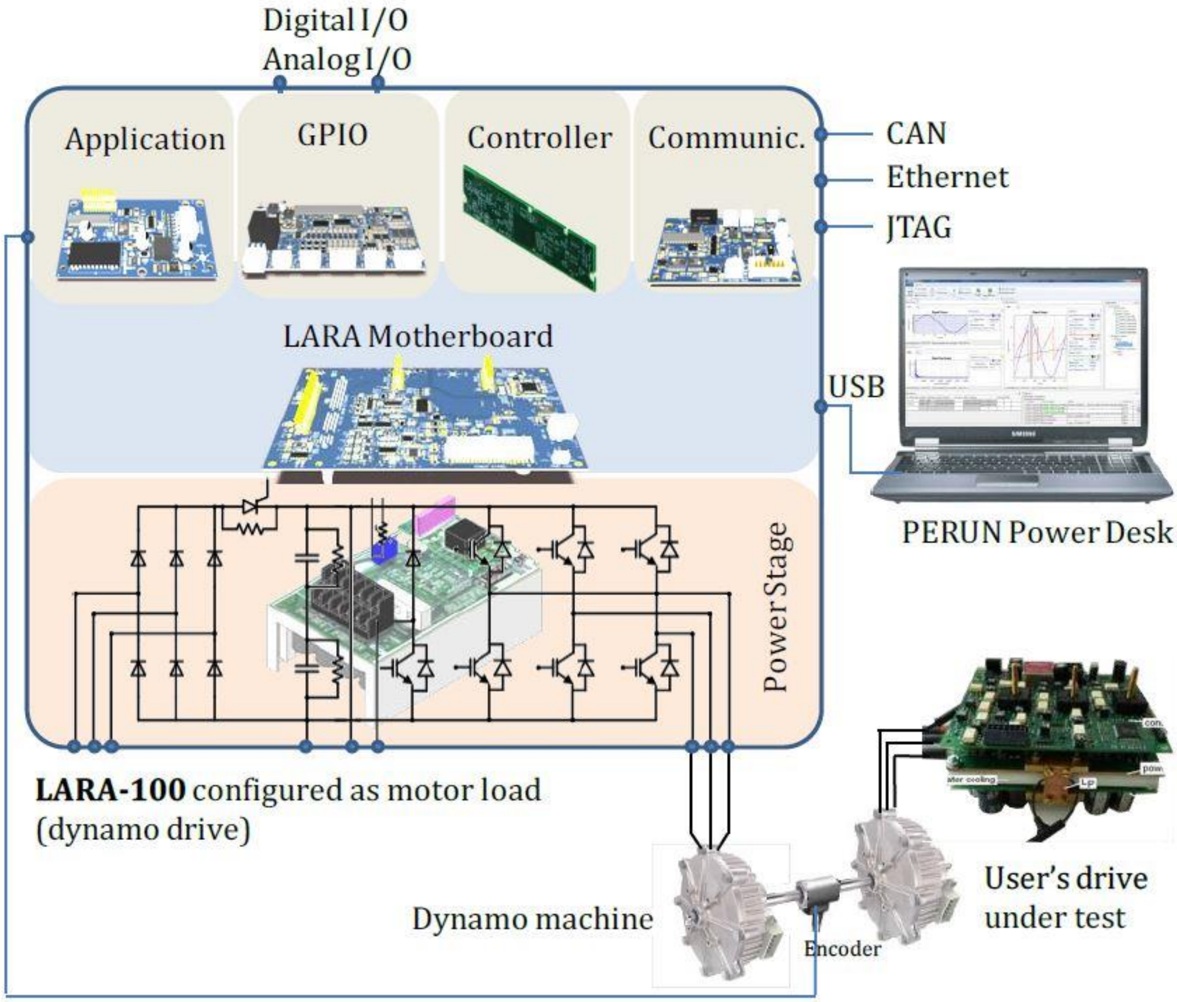

Fig. 10. A LARA-100 configured as the base of a dynamo drive (motor load.)

The dynamo machine speed measurement is procured through the Application board (APP), while the GPIO board provides relay outputs for contactors and digital outputs for signaling. The user defines the load profile in PERUN Power Desk.

Fig. 11 shows the torque and current response of the tested motor when the torque of the dynamo machine was set to 1 [p.u] (frictional type.) The reference torque assigned to the tested machine was changed from 0.5 [p.u.] to 1.5 [p.u.] at the time instant of 0.17 s. In Fig. 11 the reference and achieved torques are shown, as well as motor phase currents. In Fig. 12 we can see the zoomed details, while in Fig. 13 motor speed is displayed.

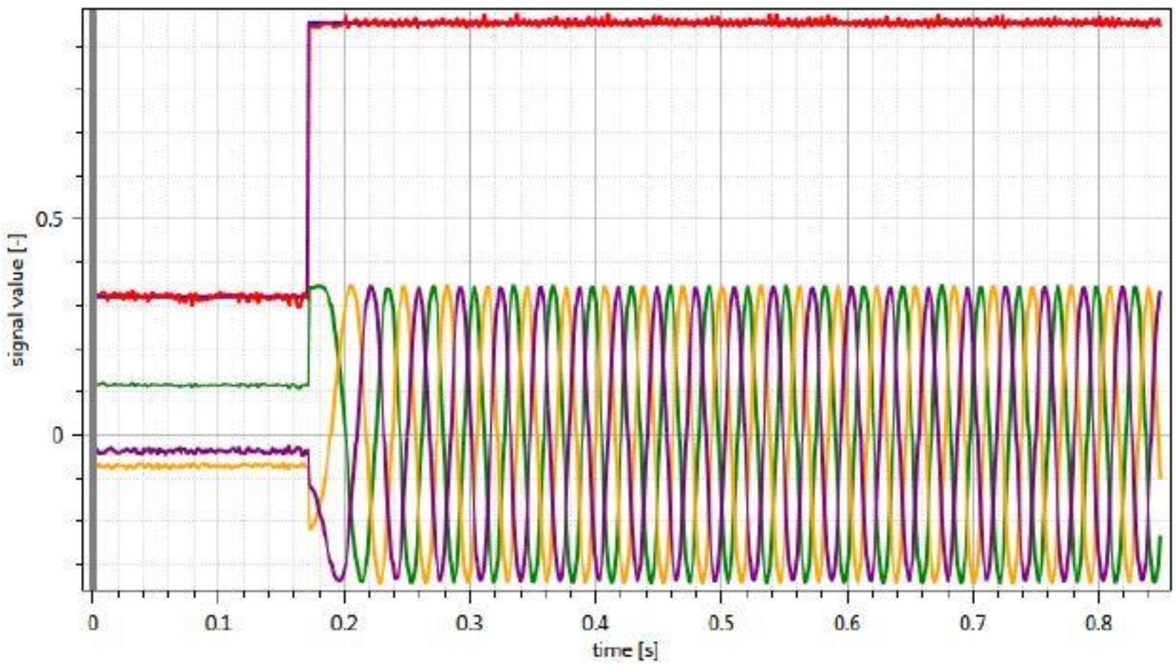

Fig. 11. Tested motor torque (reference and measured) and phase currents.

From Fig. 12 we can see that the achieved torque perfectly matches the reference torque. The motor speed (Fig. 13) was zero until the reference torque was set to 1.5 [p.u].

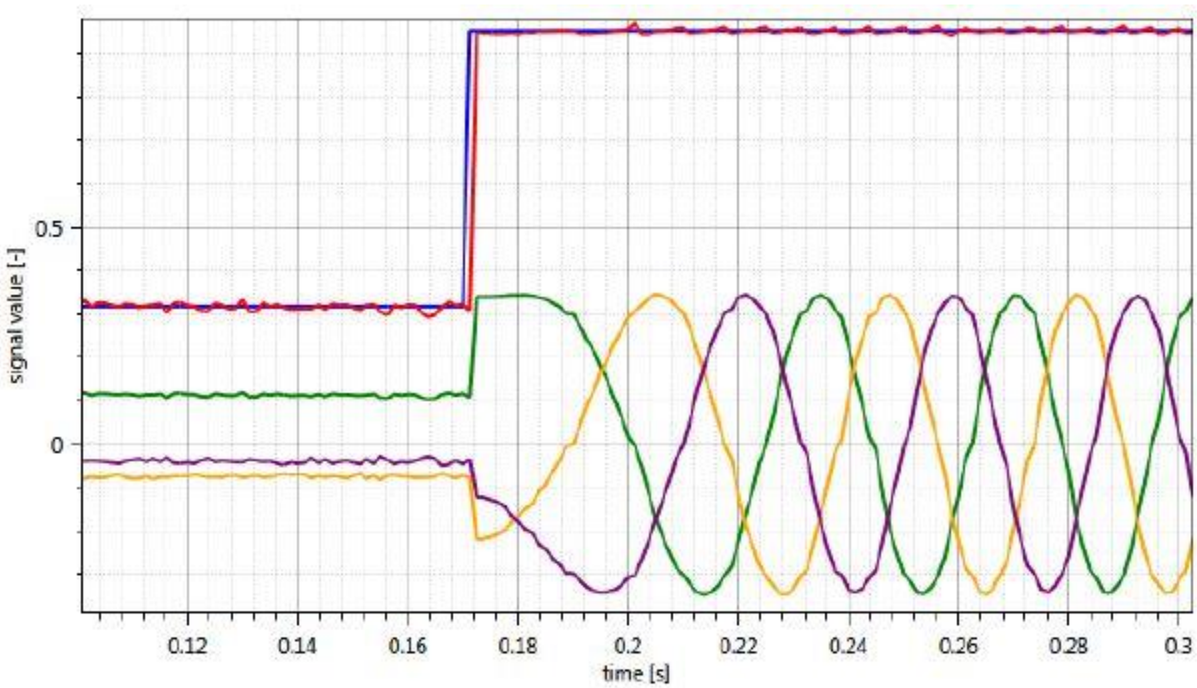

Fig. 12. Zoomed detail from Fig. 11.

Namely, prior to the instant of 0.17 s the load of 1 [p.u.] was bigger than the driving torque of 0.5 [p.u.]. Currents shown in Figs. 11 and 12 also confirm that fact.

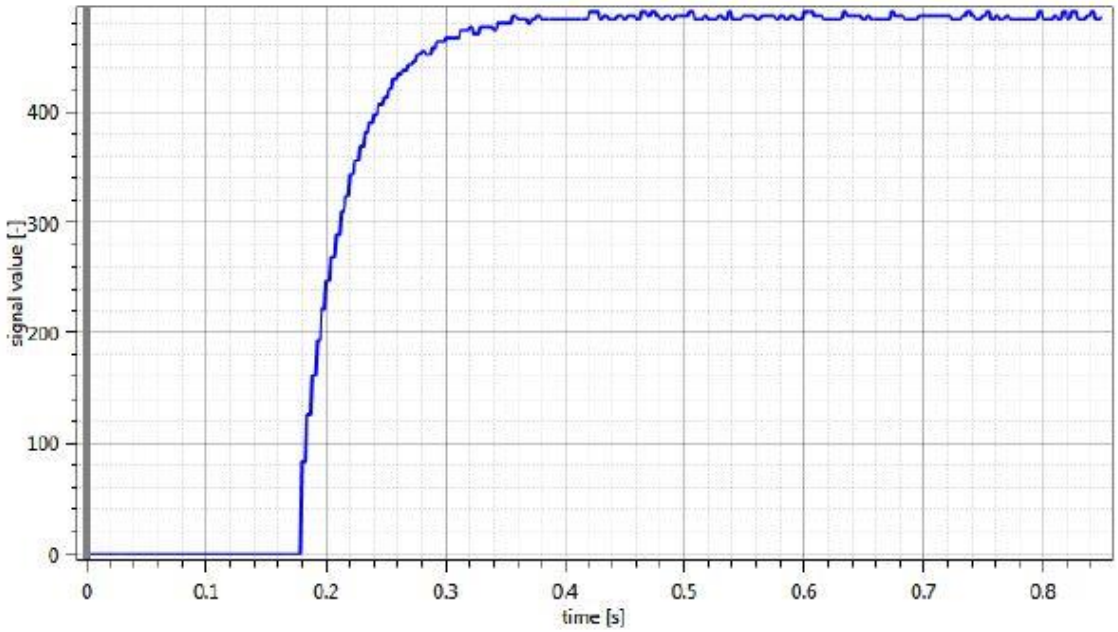

Fig. 13. Tested machine speed response.

Summary

The concept of LARA as the Launch Ramp for controller development for power electronics and power systems was demonstrated in this article through two design examples—a STATCOM and a dynamo drive. The LARA-100's re-configurability combined with its safe and flexible environment makes it a very convenient platform for engineers, researchers and academics.

About The Author

Marko Vekic, received the Dipl.-Ing., M. S. and Ph.D. degrees in electrical engineering from the Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia in 2005, 2007 and 2014, respectively. Since 2005 Marko has been employed on the Faculty of Technical Sciences in the Department of Power Electronics and Electrical Machines, first as a teaching and research assistant and then from 2014 as an assistant professor. In 2014 Marko co-founded PERUN Technologies. His expertise includes grid-connected converters and power electronics control algorithms, while his main activities are focused on product development.

Vlado B. Porobic received the Dipl.-Ing., M.S and Ph.D. degrees in electrical engineering from the Faculty of Technical Sciences, University of Novi Sad, Serbia, in 2000, 2005, and 2011, respectively. Since 2000 Vlado has been employed on the Faculty of Technical Sciences in the Department of Power Electronics and Electrical Machines, first as a teaching and research assistant and then from 2011 as an assistant professor. In 2014 Vlado co-founded PERUN Technologies. His expertise includes power electronics drives, digital signal processing, industrial communication and protocols, while his main activities *are focused on firmware development.*

Evgenije M. Adzic received the Dipl.-Ing., M. S. and Ph.D. degrees in electrical engineering from the Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia in 2005, 2007 and 2014, respectively. Since 2006 Evgenije has been employed on the Faculty of Technical Sciences in the Department of Power Electronics and Electrical Machines, first as a teaching and research assistant and then from 2014 as an assistant professor. In 2014 Evgenije co-founded PERUN Technologies. His expertise includes motor drives, grid-connected converters and power electronics interfaces, while his main activities are focused on hardware and control software development.

For further reading on design and development tools, see the How2Power Design Guide, locate the Component category and click on "Design Tools."