SYNCHRONOUSLY DRIVEN POWER CONVERTER CONTROLLER SOLUTION FOR MEDAUSTRON

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Abstract

MedAustron is an ion beam cancer therapy and research centre currently under construction in Wiener Neustadt, Austria. This facility features a synchrotron particle accelerator for light ions. Cosylab is closely working together with MedAustron on the development of a power converter controller (PCC) for the 260 deployed power converters – power supplies.

Power converters deliver power to magnets used for focusing and steering particle beams. We have designed and developed software and hardware which allows integration of different types of power converters into MedAustron's control system (MACS). PCC's role is to synchronously control and monitor connected power converters. Custom real-time fibre optics link and modular front end devices have been designed for this purpose. Modular front end devices make it possible to interface with almost any type of power converter – with or without built in regulation logic. We implemented real-time mechanisms and a dedicated real-time fibre link to satisfy requirements for synchronous control of power converters and data acquisition of their output current measurements.

MEDAUSTRON

MedAustron [1, 2, 3] is a synchrotron based accelerator for cancer treatment with protons and carbon ions. It will be used for clinical and non-clinical research in the fields of medical radiation physics, radiation biology and experimental physics. Synchrotron will deliver proton beams with energies up to 800 MeV. Three irradiation rooms are indented for medical use, one of which with a gantry, and one irradiation room for non-medical use.

INTRODUCTION

PCC is a distributed system of PXIe crates and front end devices that controls power converters. Its purpose is to ensure precise application of desired output values on power converters at precise points in time. Output value on power converters determines the magnetic field in magnets throughout the accelerator. PCC works together with MedAustron's timing system to achieve synchronous operation across all power converters. An important part of PCC is acquisition of measurements and verification of measured values against desired reference values.

POWER CONVERTER CONTROLLER – SYSTEM OVERVIEW

Output current values on power converters are set via set-points. PCC's main role is synchronous generation of set-points and acquisition of measurement results. During normal accelerator operation PCC works autonomously. Its operation is mainly dictated by the timing system. For expert or service use, PCC allows completely manual control of its functions. All of PCC's configuration parameters can be changed during runtime, which greatly simplifies and shortens commissioning and servicing of the machine.

Slow Power Converters

Slower power converters, such as those for magnets in low energy beam transport (LEBT), medium energy beam transport (MEBT) and extraction line, are controlled with single set-point values. Output on these power converters usually changes every few seconds or every few minutes. This change of output value coincides with accelerator cycles. Every accelerator cycle defines a different desired energy level of the beam.

Single set-point values are provided to the PCC in advance as a list of values associated to accelerator cycles. Optionally, when PCC is operated manually, single set-point values can be provided directly over the operator's graphical user interface and can be applied on power converter's output immediately.

PCC can provide single set-point values in different units. For example when the front end device is coupled with a digital signal processor (DSP) board, set-points can be provided as voltage, current or magnetic field. This in-house developed DSP board internally processes the received value and puts an appropriate voltage level on its analog output interface towards the power converter.

Fast Power Converters

Faster power converters, used for scanning magnets and in the main ring, are controlled with set-point sequences. Set-point sequence is a set of multiple single set-point values stored in one file. The execution of a sequence is dictated by the timing system. Graphical representation of a sequence is shown in Fig. 1.

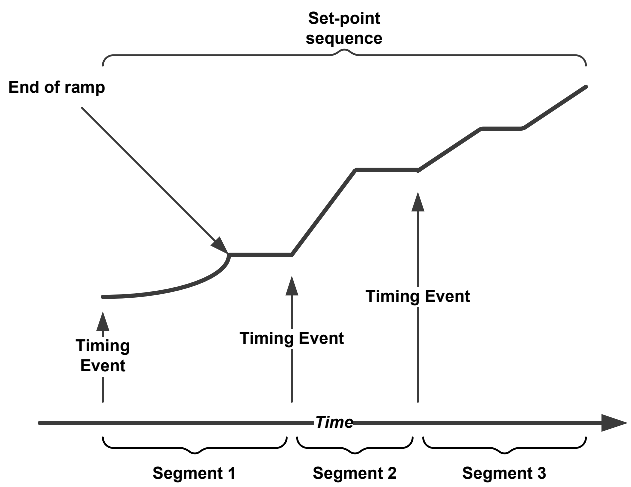

Figure 1: Structure of a set-point sequence used for fast power converters.

Output Waveform Verification

In order to verify the output of power converters against the desired reference values, PCC acquires measurements from connected power converters. Measurements are internally buffered in the PCC and optionally filtered. PCC can perform automatic verification of measured values against reference values or provide measurements to the user for inspection. Acquisition of measurements can be triggered with timing events, thus acquiring results from a specific point in time. For faster power converters, measurements are acquiread and time stamped with an accuracy of 1 microsecond.

Measurements are updated and visualized to the user in real-time, but can also be frozen. Results can be overlaid with a reference waveform from the generated set-point sequence and received timing events. This representation contains a complete set of data for the user to analyse and take advantage of in the process of fine tuning machine parameters.

Flexible Support for New Power Converter Types

Power converters with built-in logic and known set of commands can be easily integrated into the PCC. Minimal effort is required to implement a new driver in PCC application. The role of the driver is to translate power converter's set of commands into a format that is understood by the PCC application. Driver handles power converter's low level functionality and specific initialization procedures. Higher level functionality is handled by the PCC application above the driver. For expert usage and service purposes, PCC can bypass power converter driver and transparently pass commands to the power converter in raw format.

Power converters, which act as regular voltage sources, are integrated into the PCC seamlessly. Such power converters are connected to the DSP board which is attached on the front end device. Driver for the DSP board already exists and allows full configuration of parameters, e.g. for optimization of regulation loop.

TECHNOLOGY BEHIND THE POWER CONVERTER CONTROLLER

To successfully operate power converters in MedAustron's synchrotron, several challenges needed to be overcome. The most important one is synchronicity of PCC's actions. A group of fast power converters has to be synchronously controlled with an accuracy of 1 microsecond or better. Different synchronization mechanisms have to be supported. The main synchronization is dictated by the timing system, from which PCC receives timing events. Other types of synchronization include pulse synchronization and start/stop synchronization. They can be used in combination with respiratory system which is monitoring the patient and can, for example, pause and continue the operation of the PCC.

PCC Application Software

Along with hardware we designed and developed full software support. The main part of the PCC system is based on an off-the-shelf National Instruments PXIe crate, which can be seen in the middle of Fig. 2.

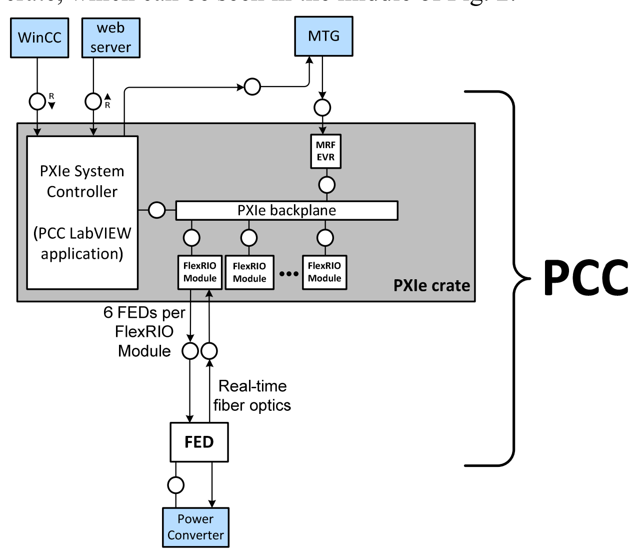

Figure 2: Architecure of PCC and interaction with other systems.

Running on the PXIe system controller are multiple instances of PCC application, integrated into MedAustron's Front End Control System (FECOS) software framework, all developed in LabVIEW. In MedAustron, PCC application is controlled and supervised over SIMATIC WinCC OA SCADA system. For expert use, PCC application can optionally be controlled with a web interface. PCC application is responsible for handling data from supervisory control system, controlled hardware and timing system, as well as specifics of different power converters: translation of power converter commands, initialization procedures, preparation of set-point values etc. For every power converter there is a dedicated PCC application instance running on the system controller. Every PCC application instance is configured with a configuration XML and configuration shared variables accessible over the network. When more power converters need to be connected, additional PCC applications are instantiated. If all slots in the PXIe crate are full, additional crate(-s) are added.

PCC application communicates with FlexRIO FPGA Modules – FPGA based cards inserted into PXIe crate slots. Firmware on FlexRIO FPGA Modules carries out time critical tasks. These tasks include transmission of data over real-time optical link, reception of timing events from the PXIe timing receiver card, generation of single set-point values and sequences, acquisition and buffering of measurement values etc. Attached onto FlexRIO FPGA Modules are FlexRIO Adapter Modules carrying optical interfaces for communication with front end devices.

FlexRIO Adapter Module with Generic Optical Interfaces

FlexRIO Adapter Module (Fig. 3) is a custom developed adapter board with 6 generic optical connectors that connects up to 6 front end devices. The adapter is completely generic and can be used for any type of application that requires multiple optical interfaces.

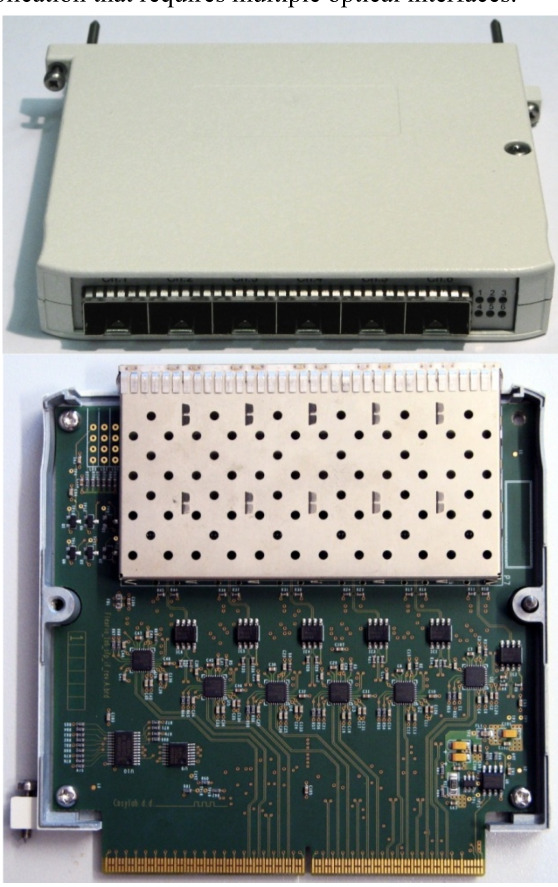

Figure 3: FlexRIO Adapter Module with 6 generic optical connectors (top – encased, bottom – PCB).

FlexRIO Adapter Module attaches onto a FlexRIO FPGA Module which takes control of the optical interfaces.

Front End Device

Front end device (Fig. 4) is an FPGA-based board which connects to a power converter directly through a RS-422 serial interface or indirectly through a DSP board. Front end device acts as a translator between the real-time fibre link and power converter's interface.

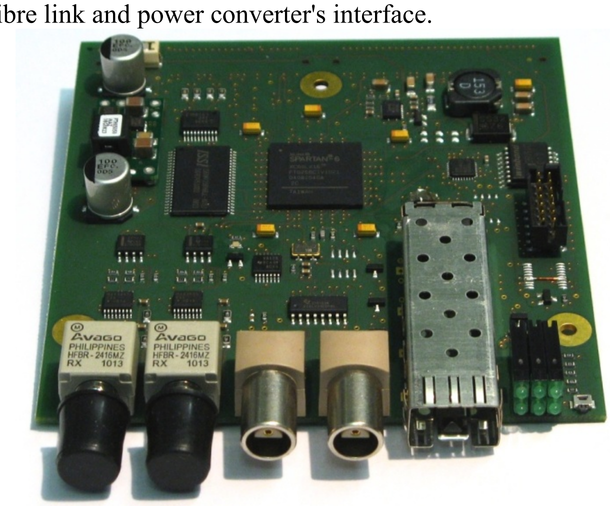

Figure 4: FPGA based front end device board.

FED plugs onto an in-house developed DSP board in case a regular voltage source power converter needs to be controlled. DSP board implements sophisticated regulation logic and regulates the output of the power converter via an analog interface.

Front end device can be located a few hundred meters away from the PXIe crate, near the actual power converter. It plugs onto a baseboard which acts as an expansion board for different I/O connectors (RS422, UHPI, trigger input and output...). Because most of the complex logic is located on the front end device, it makes it easier to design a new baseboard with connectors, if new types of interfaces are required.

Real-Time Fibre Optic Link

A custom real-time fibre optic link protocol has been designed for communication between FlexRIO Adapter Modules and front end devices. Its generic design allows it to be used for different other purposes. Its main feature is logic pipes. Each pipe has an independent interface for transmission and reception of data. Data is prioritized among the pipes by the protocol. One of the pipes has the highest priority and provides completely deterministic performance in terms of latency when data is transmitted and received. This pipe is used for transmission of set-point values (current, voltage...) towards power converters and reception of measurement values from power converters.

All logic pipes and the protocol are designed in a generic way. The protocol can be easily reused for other application requiring deterministic behaviour, plus non-deterministic transmission of background data.

CONCLUSION

Power converter controller for MedAustron is a distributed system based on off-the-shelf National Instruments PXIe hardware and custom designed modular hardware components. Modular front end device and baseboard design simplify integration with different types of power converters. Adding software support for new types of power converters requires minimal effort. PCC integrates into WinCC SCADA system and is completely configurable during runtime. PCC's operation is dictated by the timing system. Custom designed real-time fibre link protocol guarantees 1 microsecond synchronisation among different power converters. The PCC distributed system allows control of an arbitrary number of power converters of various types, making it suitable for machines of different sizes.

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