High-Density Power Converter Real-Time Control for the *Med*Austron Synchrotron

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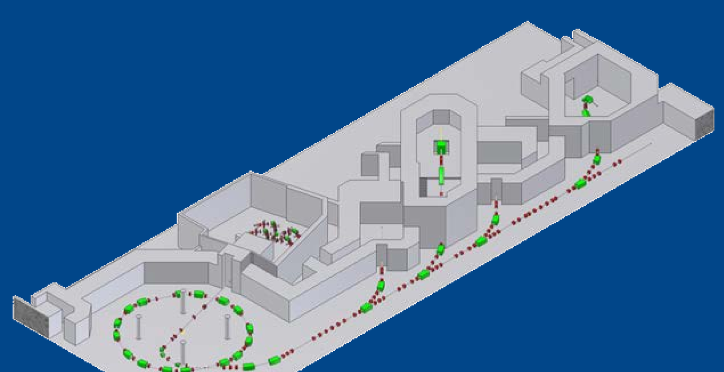
ABSTRACT

The MedAustron accelerator [1] is a synchrotron for light-ion therapy, developed under the guidance of CERN within the MedAustron-CERN collaboration. The accelerator is installed at the facility site in Wiener Neustadt, Austria. Procurement of 7 different power converter families and development of the control system were carried out concurrently. Control is optimized for unattended routine clinical operation. Therefore, finding a uniform control solution was paramount to fulfil the ambitious project plan. Another challenge was the need to operate with about 5'000 different cycles initially, scale up to tens of thousands of cycles, eventually achieving pipelined operation with cycle-to-cycle re-configuration times in the order of 250 msec. The system is based on commercial-off-the-shelf processing hardware at front-end level and on the CERN function generator design at equipment level. The system is self contained, permitting use of parts and the whole is other accelerators. Especially the separation of the power converter from the real-time regulation using CERN's generic Converter Regulation Board makes this approach an attractive choice for integrating existing power converters in new configurations.

Full-scale system deployed at facility site in data center. Power converters are remotely controlled via optical fibers at distances from 25 to 120 meters.



The accelerator, featuring four ion sources, IH-based Linac, synchrotron, three horizontal, one vertical beam line and one proton gantry. Energy ranges from 60 to 800 MeV/u, up to 250 MeV/u proton equivalent for ion therapy [2].

From the "green-field" to start of commissioning in two years from 03/2011 to 03/2013.

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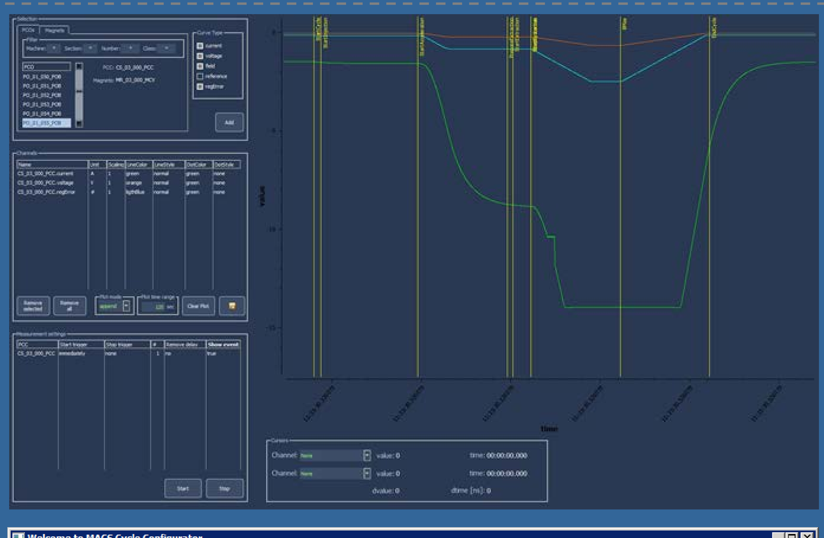
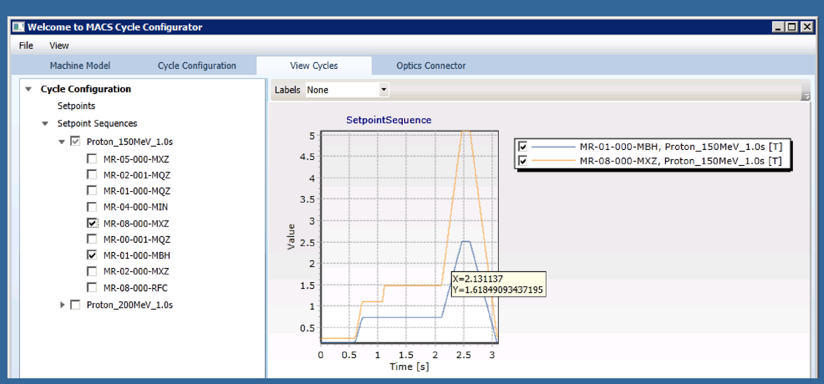
Architecture & Design: Four Tier Power Converter Control Column



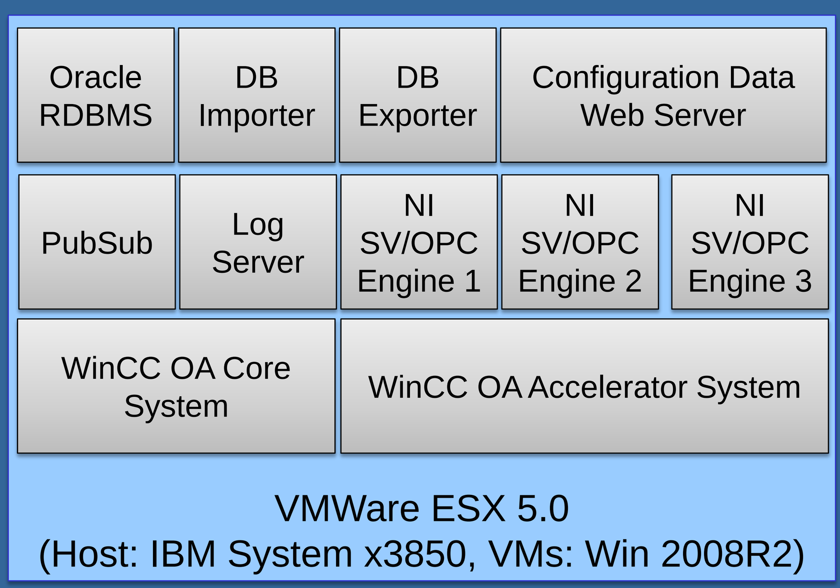


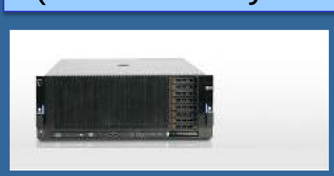
Tier-1: User Interface Panels & Applications

- Power converter/magnet circuit status
- Configuration of measurements (continuous, event triggered start/stop, repetition)
- Real-time event/waveform generation analysis
- Comparison of several measurements (value differences, time differences, precision with respect to event, display measured current, regulation error, record measurements)

Cycle Settings Generator

- C# application, **XML machine model** defines optics characteristics, **MAD-X** integrated
- Creates sampled, binary waveform files **– no modification of data from creation to generation** as risk reduction measure





- 400 GB RAM, 4 slots
- 40 CPUs @ 2.4 GHz
- 9 NICs, 5 TB local storage

Tier-2: Supervisory Control System

- **WinCC OA** for monitoring, state machines of applications and power converters, interactive setpoint provision and measurement, configuration of frontend controller [3]
- DB exporter configures WinCC OA, shared variable/OPC, export data to Web server
- **Publisher/subscriber** (C#, Labview bindings) for measurement acquisition
- **Versioned** binary **waveform** data, ASCII **setpoint** data, **crate configuration on Web server** –frontend controller libraries download automatically on startup of application.

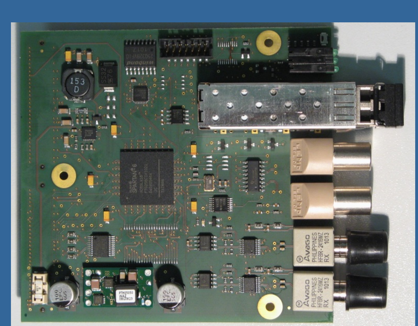
- NI PXIe-8135 CPU, PXIe-1082 8 slot crate
- Windows 7 64bit, Labview 2010 SP1
- MRF PXIe EVR300 event receiver card
- 9 crates for up to 324 power converters

Tier-3: Frontend Controller

- **Receives events** [4] triggering value / waveform generation and re-configuration (PXIe event receiver card from Micro Research Finland in MedAustron case)
- **Configuration** settings and waveforms on local disk, **cached into memory as needed**
- **Reconfigures FlexRIOs** for next cycle while current cycle setpoint/waveform is generated
- Application on non-RT Windows 7
- **Links to SCADA** (WinCC OA) via SV/OPC and in-house developed publisher/subscriber
- **Transmits setpoints in real-time to 36 power converters** at configurable rate with less than 1 µsec jitter (2 kHz for this case)

Tier 3 to Tier 4 link: Optical FlexRIO Adapter 6 SFPs

- **Real-time data transmission via FlexRIO** FPGA **+ optical link**
- 100 kValues/sec real-time data protocol, 1 µsec value precision
- Bidirectional, 2 value streams down, 4 value streams up
- **Non-RT channels**, UART protocol for status, slow control, configuration of power converters
- **Trigger with 1 µsec precision** over the same optical fiber to save expensive timing cards and extra fibers



Generic Adapter Board (Front End Driver)

- Spartan 6 based, low cost, implements real-time protocol
- **Clock recovery** from opto-link, GPS and phase synced – no drift!
- Optical and/or electrical **triggers**, GPIO to power converter
- RS232 and RS422 **serial links** to power converter
- **UHPI bus interface** to communicate with DSP board in real-time

Tier 4: Converter Regulation Board (CRB)

Interfaces to power converters for slow control and performs digital real-time regulation with analogue voltage reference output to PCO

- **Derived from CERN Function Generator Card** (FGC) [5]
- Low cost, turnkey integration via contractor
- C programmable, bus interface (32 bit UHPI)
- TI floating point **DSP + FPGA** Xilinx Spartan 6
- 8 Mbytes Flash + 32 Mbytes DRAM
- 32 **digital Input/Output** pins
- **Temperature** reading (0.1 C precision) to improve regulation stability
- **ADCs**: 2x100 kHz@16 bits, 2x40 kHz@19 bits
- **DAC**: 1x16 bits, conversion time < 10 µsec
- High speed **LVDS** serial: 3 x input, 3 x output, 1 x USB for configuration

Key Requirements

Uniform control of all power converters

- 7 different suppliers
- Control system developed concurrent to PCO engineering and tendering

Concurrent control and reconfiguration

- Medical irradiation = sequence of different cycles = different settings
- Cycle-to-cycle configuration in 250 msec

Simplified system management

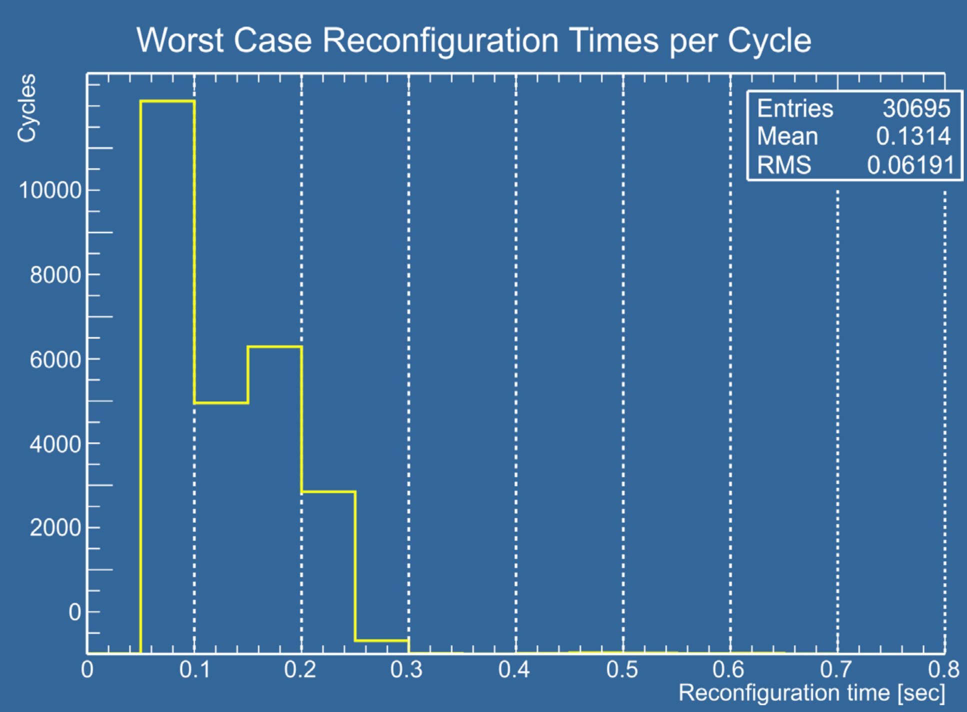
- 300 power converters in 800 m2 hall
- Reduce number of controllers
- Control at a distance (150 meters)

High performance & reliability

- 5000 – 10000 different cycles
- Synchronize 100 power converters at 1 µsec & 10 PCOs at 10 nsec precision
- Safe operation for clinical mode

Performance

Performance evaluation revealed that the original implementation achieved average cycle-to-cycle re-configuration of 450 msec on average with worst cases up to 2.5 seconds. After code optimization, the **average worst case re-configuration time** per cycle over all PCC applications and crates was brought down to **131 msec** (62 msec RMS). For **0.015%**, worst cases **between 300 and 700 msec** were observed. An **acknowledgement mechanism** from all PCC crates to the timing event generator can be used to postpone the next cycle generation until re-configuration has completed successfully.



Slowest re-configuration time observed of all PCC application components measured for each cycle.

SUMMARY

The full scale control system [6] has been installed and handed over for accelerator commissioning in July 2013. On-site tests with simulators and real power converters were carried out. Performance was evaluated and optimizations have been implemented. The system is currently used for injector commissioning.

REFERENCES

[1] M. Benedikt and A. Wrulich, "MedAustron-Project overview and status", Eur. Phys. J. Plus 126 (2011) 69

[2] M. Benedikt, U. Dorda, J. Gutleber et. Al., "Overview of the MedAustron design and technology choices", 1st IPAC, Kyoto, Japan, May 23-28 2010, pp. MOPEA020

[3] M. Marchhart, A. Gutleber, R. Moser et al., "Extending WinCC OA for Use as Accelerator Control System Core", Proc. ICALEPCS 2013, San Francisco, USA

[4] J. Gutleber, Z. Croflic, J. Dedic et. al., "A Timing System for Cycle Based Accelerators", Proc. ICALEPCS 2013, San Francisco, USA

[5] D. Calcoen, Q. King, P.F. Semanaz, "Evolution of the CERN Power Converter Function Generator/Controller for Operation in Fast Cycling Accelerators", Proc. ICALEPCS 2011, Grenoble, France, WEPMN026

[6] The MedAustron Accelerator Control System: Design, Installation and Commissioning, Proc. ICALEPCS 2013, San Francisco, USA