A NEW GENERATION OF DIGITAL POWER SUPPLY CONTROLLERS

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Abstract

In accelerator applications, high precision, high speed power supplies (PS) for magnets are needed to guarantee a high beam quality. For an optimal control of these PS, the presented second generation of a Digital Power Electronic Control System (DPC) has been designed and successfully applied at PSI (Paul Scherrer Institute). The main components of the DPC are the Controller Card (DPC_CC) and the high precision Analogue to Digital converter card (DPC_AD) shown in Figure 1. Compared to the first generation digital Power Supply Control (PSC) precision, acquisition rate, processing power and functionality have been improved considerably. This allows faster control cycles and/or more complex control algorithms. The DPC_CC now features 12 standard precision (16 bit) ADC channels and allows the simultaneous control of multiple PS. High precision requirements are met by adding the DPC_AD to the system. The modular and flexible design allows well-matched solutions for the typically heterogeneous accelerator PS.

Figure 1: DPC_CC- and DPC_AD- card.

HISTORY AND MOTIVATION

Starting in 1999, a large number of fully digitally controlled magnet PSs are in operation at the Swiss Light Source (SLS) of PSI [2] [3]. Since then, PSC has been increasingly used in other PSI accelerators as well as different light sources worldwide. Today, about 1000 units of this first generation PSC are in operation at PSI and further 2700 PS worldwide.

The design of the new controller generation was launched in 2007. Significant improvement of accuracy and speed were the main motivation of this project.

OVERVIEW

The DPC consists of a controller card (DPC_CC), a high precision AD-converter (DPC_AD) and a backplane (DPC_BP). The backplane contains common connectors as well as fibre optic transmitters and receivers for the PWM. All analogue and digital signal paths are electrically isolated to avoid ground loops and increase the immunity to interferences.

The structure of a PS based on the DPC, including the interfaces to the control system, is shown in the block diagram in Figure 2.

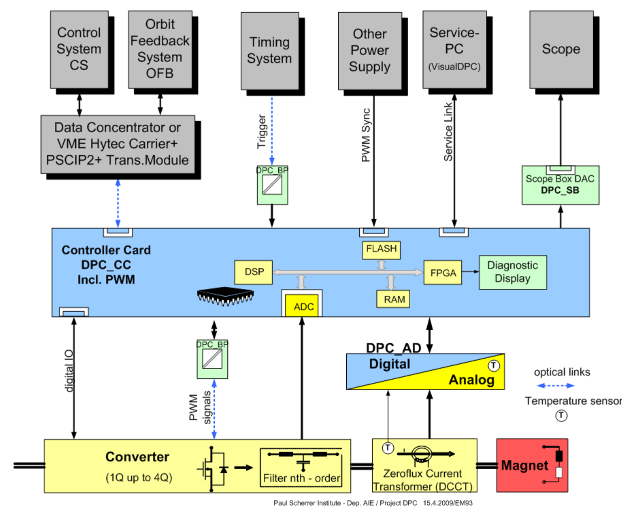

Figure 2: Power supply control using DPC_CC and_AD.

The core of the DPC_CC is a FPGA which handles all the communication links, the pulse width modulation PWM [1] and many other tasks. The closed loop control itself is processed by a floating point DSP with a control cycle frequency of up to 200 kHz. Alternatively, the controller can handle two PS simultaneously with 100 kHz.

A new feature of the controller card are the 12 independent, simultaneously sampling 16 bit AD converters (200 ksps). This allows cost-efficient designs without DPC_AD for lower stability and precision requirements. The performance of the onboard ADC is listed in Table 1.

Table 1: Specifications of the onboard ADCs

Parameter	Comment	Typ	Unit
Offset error	calibrated channels uncalibrated channels	±10 ±45	ppm
Gain error	calibrated channels uncalibrated channels	±500 ±1000	ppm
Noise (RMS)	@ 100kHz control cycle; @ 10 kHz control cycle; @ 1 kHz control cycle;	20 6 2	ppm
Repro-ducibility	after shutdown	±10	ppm
Stability	over 24 hours	±10	ppm
Longterm stability	over 500 hours	±10	ppm
Temperature sensitivity	offset and gain	±3	ppm / °C

For special applications, it is also possible to store and run reference current waveforms on the controller card. The waveforms can be started with an external trigger. Multiple PS can operate in a phase locked state by means of a PWM Sync signal. A small LCD display shows basic information of the PS status.

HIGH PRECISION AD CONVERTER (DPC_AD)

For high precision applications the single channel AD-converter card DPC_AD shown in Figure 3 was developed. It has a basic resolution of 18 bit and a sampling rate of 600 kHz which allows oversampling for an additional increase of the resolution. Additionally, it has temperature stabilization and an onboard error correction. The offline analysis and sophisticated calibration is performed with the calibrator described in [5]. The resulting error correction function is stored in a flash memory (correction LUT). The accuracy of subsequent conversions is improved by adding this value to the ADC raw data. Thanks to the excellent long-term stability of the chosen reference, gain and offset calibration can be verified automatically when the PS is switching-on.

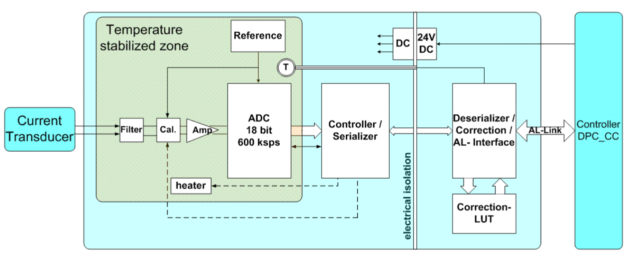

Figure 3: Block diagram of the AD-converter DPC_AD.

Stability

The stability of a PS is mainly determined by the current transducer and the AD-conversion.

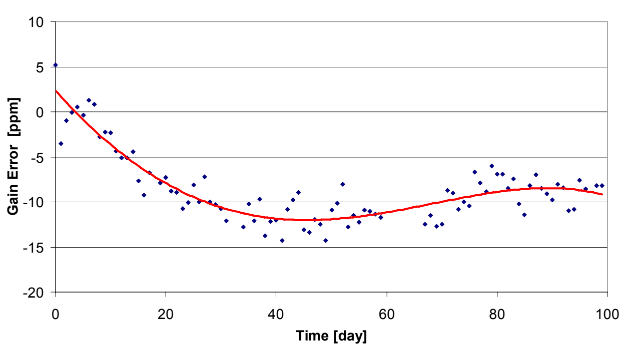

Figure 4: Long-term stability of gain error.

For the following considerations the current transducer is assumed to be stable. The short-term stability [8h] of the DPC_AD is within ±5 ppm. The long-term stability of the gain error has been measured over a period of 100 days (Figure 4). After a burn-in period of two weeks (AD and nearby elements on operating temperature of 65 ˚C), the long-term stability of the gain error is within a range of 10 ppm.

Temperature sensitivity

Temperature stabilisation of input amplifier, AD-converter and reference reduces the sensitivity to variations of the board ambient temperature. While the ambient temperature varies between 10 ˚C and 45 ˚C the temperature sensitivity is below ±0.5 ppm/˚C and outside of this range about ±1.8 ppm/˚C.
The performance of the DPC_AD is listed in Table 2.

Table 2: Specifications of the DPC_AD card

Parameter	Comment	Typ	Unit
Offset error	calibrated	±5	ppm
Gain Error	calibrated	±10	ppm
Noise (RMS)	@ 100 kHz control cycle	3	ppm
	@ 10 kHz control cycle	1	
	@ 1 kHz control cycle	0.3	
Repro-ducibility	after shutdown	±5	ppm
Linearity		±2	ppm
Stability	over 24 hours	±5	ppm
Longterm stability	over 1000 hours	±10	ppm
Temperature sensitivity	gain and offset between 10 and 45˚	<±0.5	ppm/˚C
Temperature sensitivity	gain and offset below 10 or above 45˚	±1.8	ppm/˚C

COMMISSIONING TOOLS

Today, the well established Service Tool VisualECS running on a PC (Figure 5), connected via RS232 to the controller card, is used for commissioning and maintenance of DPC applications. Its successor (VisualDPC) is under development and will provide more functionality, for example Ethernet as service link.

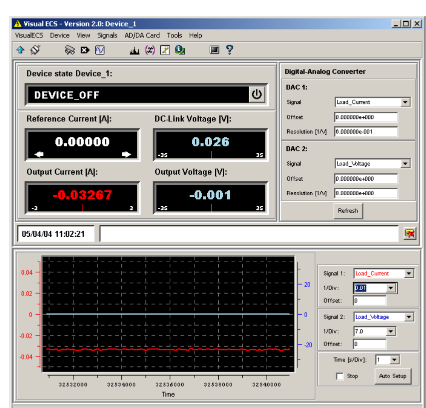

Figure 5: VisualECS GUI running on PC.

The Scope Box - a commissioning tool - contains a 4 channel DAC. Thus, 4 digital process values can be selected, processed with offset and gain and converted to the analogue equivalent for real time measurement with an oscilloscope. The update rate of the DAC is 200 kHz, the resolution 16 bits and the output voltage range +/- 10 V.

RESULTS

Closed loop bandwitdh

The limiting factors of high speed magnet power supplies are measurement delay, control cycle time and PWM period. Compared to PSC they have been reduced considerably. This leads to a faster step response and a higher control bandwidth, with the same control algorithms. The achievable dynamic behavior of a corrector PS, controlled with a DPC and a standard PSC, are shown in Table 3.

Table 3: Achievable dynamic behaviour

Controller type	Delay [µs]	Control Cycle [µs]	PWM- half-period [µs]	Step Response [µs]	Approx. Bandwidth [kHz]
PSC	30	20	5	230	2.5
DPC	17.7	10	5	170	3.6
DPC	17.7	5	5	160	3.9
DPC+	17.7	5	5	50	10

With new control structures [6] which are currently developed the speed of digitally controlled power supplies can be increased further. The results of these investigations are listed under DPC+.

Resolution

A high resolution PWM [1] together with low inherent noise in the signal path, are required to achieve the resolution shown in Figure 6.

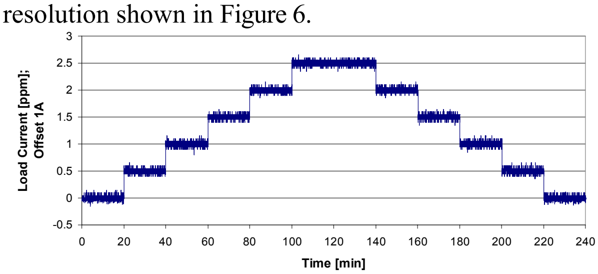

Figure 6: Resolution and reproducibility with 0.5 ppm steps.

The picture, measured on a +/-10A corrector PS, shows small 0.5 ppm steps (equivalent to 5 µA) superimposed to an offset current of 1 A. The depicted current is filtered with a 1 Hz lowpass filter.

Applications

The controller has been designed for various applications: General power electronics applications with / without DPC_AD; Control of a fast single high precision PS using DPC_AD; Control of up to three PS with a precision of 1‰ without using DPC_AD. The third application leads to compact solutions and reduces the expenses per PS significantly.

Integration into control system

Two different communication links to the control system are provided: The CP_F-link, which is based on the same physical layer (plastic optical fiber) as the existing PSC control link. But, the frame rate has been increased to 100 kHz by using 8b/10b coding. A newly designed DPC-data-concentrator can handle up to 8 controllers and provides a Gigabit-Ethernet link to the control system as well as a RocketIO-link to the fast orbit feedback system. For standalone applications the Ethernet service link can also be used as communication link.

CONCLUSIONS

The presented, flexible to use, digital control platform is based on state of the art technology. Besides the increased speed, precision and stability, it allows the control of up to three PS with one controller only. It is expected to cover the requirements of the next ten years for most applications.

The first 120 PS with DPC_CC and _AD are currently put into operation in the 250 MeV injector at PSI, a pre-project of the SwissFEL (http://fel.web.psi.ch/). Further 600 PS for the SwissFEL are already planned.

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