THE FULLY DIGITAL CONTROLLED CORRECTOR MAGNET POWER CONVERTER

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Abstract

This paper presents an implementation of a precision corrector magnet power converter, which is capable of delivering ±10A/±50V output, by using the digitally controlled pulse width modulation method. The output current precision of this corrector magnet power converter is within the +/-10ppm criteria. The digital control circuit of the power converter is implemented by using a high speed ADS8382 18-bits analog-to-digital converter and a TMS320F28335 digital signal processor. The converter uses a full bridge configuration, the switching frequency of power MOSFET is 40 kHz and the control resolution is 17-bits. Using a DCCT as the current feedback component the output current ripple of the converter could be lower than 5 ppm which is beyond the requirement of current TLS corrector power converter and qualified to be used in the future TPS facility.

INTRODUCTION

In storage ring of TLS, the Bira MCOR30 power modules are used as the corrector magnet power converters, the regulation of the MCOR30 power module is convectional analog control. For the new TPS project, fully digital control corrector magnet power converters are considered to be adopted and installed for future operation in 2012. Therefore, the power supply group of NSRRC is now studying and developing a stand-alone module board in which digital regulation control is implemented and the control parameters can be downloaded and adjusted on the fly according to different kind of magnet loads.

To confirm the accuracy of digital regulation control policy before implementation of the circuitry, this digital regulation corrector magnet power converter is simulated with Matlab simulink, the behavior of full bridge configuration power converter and the P-I compensator are included. There are three main components are embedded in the digital regulation control circuit, Texas Instrument TMS320F28335 DSP controller、high speed ADS8382 18-bits ADC and Danfysik Ultrastab 866-20I DCCT, and the performance is verified by using the MCOR30 power module as the platform. With this digital regulation control circuit PWM signal is produced to gating the MOSET and the output current ripple is well controlled below ±10ppm that meets the specification of corrector magnet power converter.

THE STRUCTURE OF CORRECTOR MAGNET POWER CONVERTER

The corrector magnet power converter could be roughly divided into five functional blocks: Power regulation and filtering /high precision current feedback system / high speed ADS8382 18-bits analog-to-digital converter/ DSP TMS320F28335 controller and USB/JTAG transmission interface. Figure 1(a) shows the structure of corrector magnet power converter and the red block is the function block digital regulation circuit, Figure 1(b) is the picture of the digital regulation circuit board.

(a)

(b)

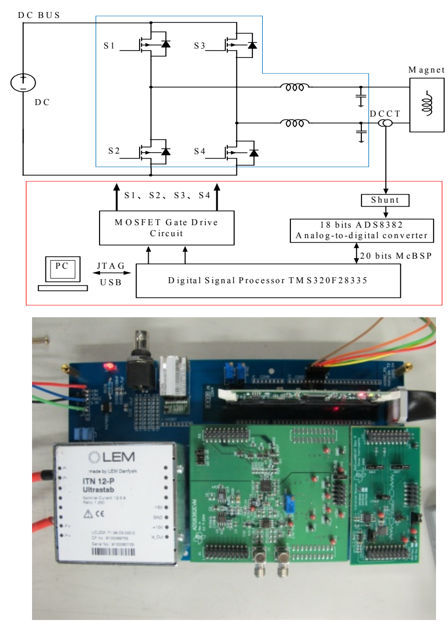

Figure 1: (a) The structure of corrector magnet power converter; (b) The digital regulation circuit board.

SIMULATION OF THE CONTROL POLICY

For confirmation of control policy accuracy and applicability of the digital regulation control circuit, the behaviors of digital regulation control circuit and P-I compensator are simulated with Matlab simulink.

The circuit diagram for simulation is demonstrated in Figure 2(a), and this circuit diagram includes the full bridge configuration power MOSFET、the output filter、the P-I compensator and PWM controller. Figure 2(b) is the internal block diagram of P-I controller, there are two main functions inside the block diagram of P-I controller, P-I compensation and PWM signal generation. The P-I compensator will generate an error signal by comparing the current reference and the current feedback signal from DCCT, then the error signal is imported into PWM controller compared with the triangle carrier to generate PWM signal to drive MOSFET switch.

(a)

(b)

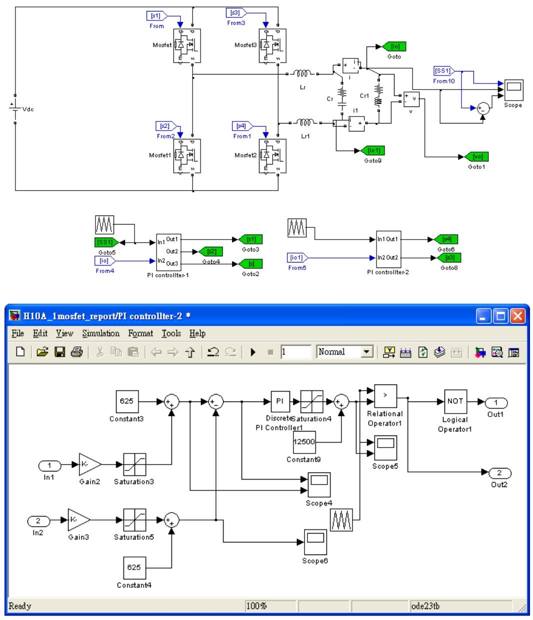

Figure 2: (a) The system circuit diagram; (b) P-I compensator internal block diagram

There are three waveforms simulated and demonstrated in Figure 3, the top one is the simulated input reference command, the second one is the simulation result of current output and the bottom one is the waveform of error signal that is the difference between the simulated input reference command and the simulation result of current output.

Input Reference →

Output Current →

Current Error→

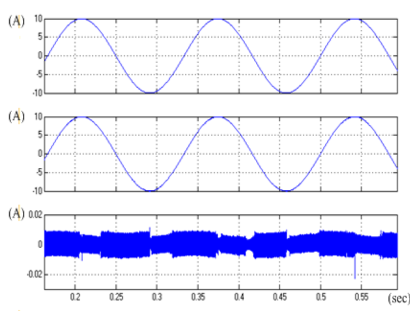

Figure 3: MATLAB simulink simulation result of P-I compensator

HIGH PRECISION CURRENT FEEDBACK SYSTEM

Low ripple、high stability and accuracy output current are the requirements of the corrector magnet power converter. The key component of the corrector magnet power converter to meet requirements is the current sensors. Here we adopt the Danfysik Ultrastab 866-20I DCCT[2] (Figure 4) as the current feedback element.

The current transfer ratio of Danfysik Ultrastab 866-20I DCCT is 250, in feedback circuit there is a 25Ω burden resister in series with the output of DCCT and voltage signal on burden resister is amplified 4 times then fed into error amplifier to compare with current reference signal.

Figure 4: Danfysik Ultrastab 866-20I DCCT

HIGH SPEED ANALOG-TO-DIGITAL CONVERTER

In order to generate the accurate digital current feedback signal for DSP to do digital regulation process, a high resolution analog-to-digital converter must be inserted between DCCT and DSP. In this digital regulation circuit, a TI ADS8382 A/D converter is used to convert the analogy DCCT current signal to digital current signal and import into DSP. The TI ADS8382 A/D converter is a high performance 18-bits analog-to-digital converter with some characteristics, 600kHz sample rate、SPI interface and pseudo-bipolar. Figure 5 is the timing graph of ADS8382, the sampling time is 83.3kHz.

System clock →

Chip select →

Frame Synchronization →

Conversion signal →

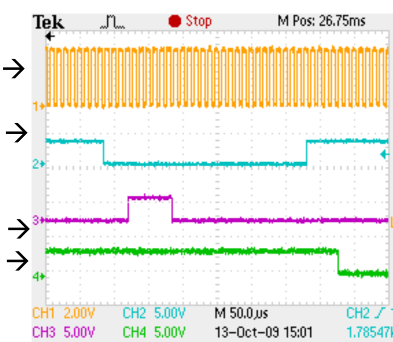

Figure 5: The timing graph of ADS8382

After converting analogy out current signal into digital data by ADS8382, the data will be transferred to internal data register of DSP28335, and the data waveform is shown in Figure 6.

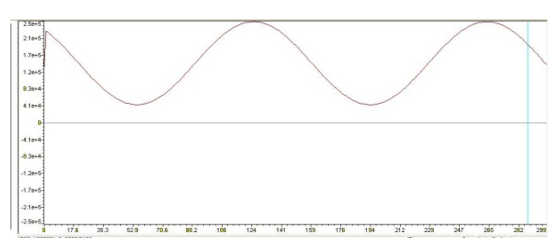

Figure 6: The waveform stored in DSP's data register

DIGITAL SIGNAL PROCESSOR

The core element of fully digital controlled corrector magnet power converter is a TI's TMS320F28335DSP. The program for this DSP to regulate output current is developed, and this program includes five main functions, interruptive event、 A/D timing、 P-I compensation、low pass filter and high resolution PWM signal output. Figure 7 is the DSP control command and the quantity of P-I compensation.

P-I Compensation →

Command→

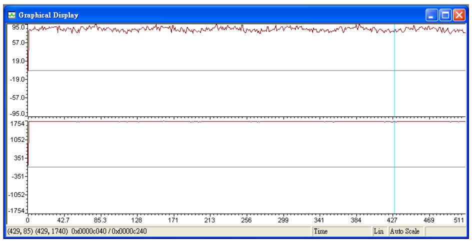

Figure 7: DSP control command and the quantity of P-I compensation

The testing profile of reference command for this digital corrector magnet power converter is a sinusoidal waveform. Figure 8 is the relation between reference command and output current signal, it's obvious the output current faithfully follows the reference command.

Reference Command →

Output current →

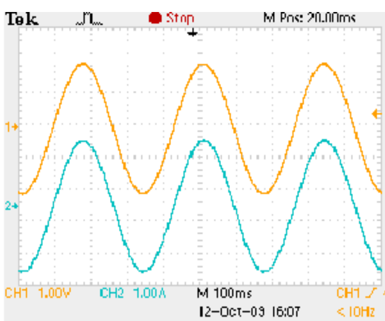

Figure 8: Relation between the sinusoidal testing signal and the output current

The ripple of output current is measured, the ripple current floor is about 1μA(0.1ppm) and the 60Hz ripple is the biggest ripple component that is under 30μA(3ppm), and frequency spectrum of output current is demonstrated at Figure 9.

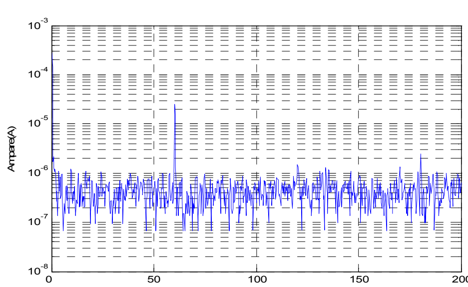

Figure 9: frequency spectrum of output current

Figure 10 shows the output current stability of the corrector magnet power converter with duration of 16 hours, and the stability is within 5ppm.

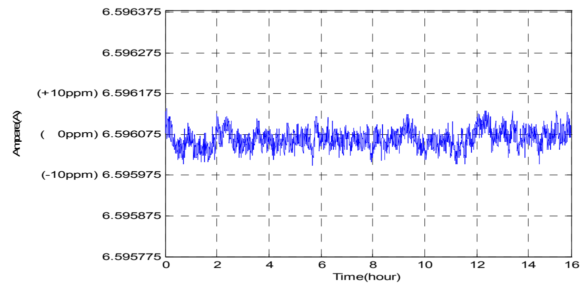

Figure 10: Stability of output current

CONCLUSION

A new generation of power supply with a digital signal processor embedded inside of regulation circuit to fulfill a digital regulation power converter is developed by power supply group, NSRRC. The output current ripple of this fully digital controlled corrector magnet power converter is under 30uA, and output current stability is about 5ppm with testing duration of 16 hours, the performance is better than the requirement to power corrector magnet. This power convertor is a prototype, in the future, we will integrate monitoring of some important parameters、 protection function and interlock status into the digital regulation circuit and communicated with external control system by Ethernet interface.

REFERENCES

[1] William J. Palm III, "MATLAB for Engineering Applicatons", McGraw-Hill,Inc., 1999.

[2] Danfysik Ultrastab 866-20I, http://www.danfysikacp.com.

[3] MS320F283xDSP Technical Reference, http://www.ti.com.