# N+1 REDUNDANCY POWER SUPPLY SYSTEM BY PARALLELING CURRENT CONVERTER MODULES WITH DIGITAL REGULATION CONTROL

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*Abstract*

The N+1 redundancy power supply system is fulfilled with adopting the Bira System MCOR30s as a platform, eight pieces of Bira MCOR 30 power converter boards are installed at crate 2512 and outputs are connected together, the output current of these paralleled eight Bira MCOR 30 power converters are regulated by an external homemade digital control circuit. With homemade digital control circuit, these paralleled eight Bira MCOR 30 power converter modules could deliver up to 240A/30V with ±20ppm precision and stability. The digital regulation control circuit of the N+1 redundancy power supply system is implemented by using a multi-channel DAC5868 16-bits digital-to-analog converter (DAC), a high speed AD8382 18-bits analog-to-digital converter and a TMS320F28335 digital signal processor (DSP). The update reference voltage frequency of DAC is 83.3 kHz. A DCCT is used as the current feedback component and the output current ripple of the N+1 redundancy power supply system is lower than 20ppm which is beyond the requirement of current TLS quadruple and sextuple power supplies and qualified to be used in the future TPS facility.[1~2]

## INTRODUCTION

In the storage ring of TLS, the Bria MCOR 30 power modules are used as the corrector magnet power converters, the regulation of the MCOR 30 power module is convectional analog control, the amount of the MCOR 30 power modules have 123 piece. For the new TPS project, the digital control quadruple and sextuple magnet power converters are considered to be adopted and installed for future operation in 2014. Therefore, the power supply group of NSRRC is now studying and developing a N+1 redundancy power paralleling current converter modules in which digital regulation control is implemented and the voltage reference can be changed on the fly according to different paralleling current amount of Bira MCOR 30 power modules.

To confirm the accuracy of digital regulation control policy before implementation of the circuitry, this N+1 redundancy power paralleling current converter modules is simulated with MATLAB simulink, the behavior of Bira MCOR30 configuration, power paralleling current converter structure and the P-I compensator are included. There are four main components are embedded in the digital regulation control circuit, Texas Instrument TMS320F28335 DSP controller, multi-channel DAC5868 16-bits DAC converter, high speed ADS8382 18-bits ADS and LEM IT 600-S Ultrastab DCCT, and the performance is verified by using the MCOR30 power module and Bira Crate 2512 as the platform. With this digital regulation control circuit, output current control reference signal voltage is connected to everyone MCOR30 converter board and the output current ripple is well controlled below ±20ppm that meets the specification of quadruple and sextuple magnet power converter.

## THE STRUCTURE OF N+1 REDUNDANCY POWER SUPPLY

The N+1 redundancy power supply could be roughly divided into five functional blocks: Bira MCOR 30 power modules and Bira MCOR crate 2512/ high speed AD8382 18-bits analog-to-digital converter/ multi-channel DAC5868 16-bits digital-to-analog converter/ DSP TMS320F28335 controller and USB/JTAG transmission interface. Figure 1 shows the structure of N+1redundancy power supply circuit, Figure 2 is the Bira MCOR 30 power converter module boards and MCOR Crate2512.

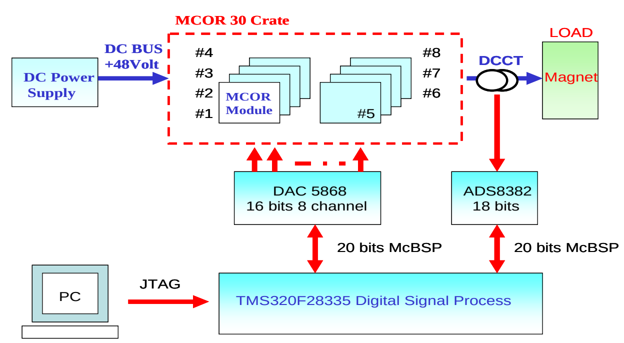


Figure 1: The structure of N+1 redundancy power converter.

Figure 2: The Bira MCOR30 power converter board and Bira MCOR Crate2512.

## SIMULATON OF THE CONTROL POLICY

In order to confirm accuracy of control policy and applicability of the digital regulation control circuit, the behaviors of digital regulation control circuit, P-I compensator and MCOR 30 power converter modules are simulated with MATLAB simulink.

The circuit structure for simulation includes the Bria MCOR30 modules configuration, analog regulation of the MCOR 30 modules, P-I compensator and division current command block. Figure 3 is the block diagram of P-I compensator, that is made up of two main functions respectively for P-I compensator and shunt command block. 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 shunt command block divided by parallel quantity to generate compensation signal to Bira MCOR 30 converter modules voltage reference.

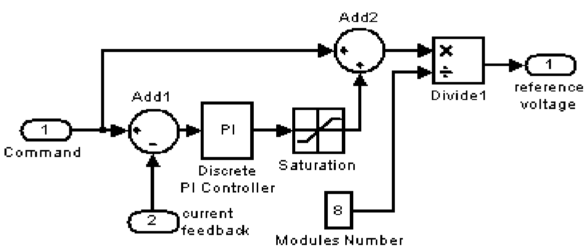


Figure 3: P-I compensator internal block diagram.

There are three waveforms simulated and demonstrated in figure 4, the top one is the DC 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.

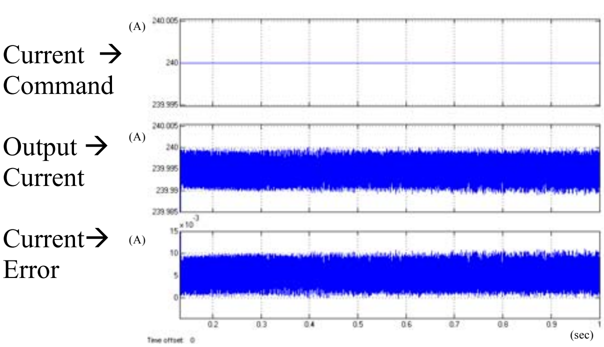


Figure 4: MATLAB simulink simulation result of P-I compensator.

## HIGH PRECISION CURRENT FEEDBACK SYSTEM

Low ripple, high stability and accuracy output current are the requirements of the N+1 redundancy power supply converter. The key component of the N+1 redundancy power supply converter to meet requirements is the current sensor. Here we adopt the LEM IT 600-S Ultrastab DCCT(Figure 5) as the current feedback element.

The current transfer ratio of LEM IT 600-S Ultrastab DCCT is 250, in feedback circuit there is a 5Ω burden resister in series with the output of DCCT and voltage signal on burden resister is amplified 75 times then fed into error amplifier to compare with current reference signal.


Figure 5: LEM IT 600-S Ultrastab DCCT.

## DIGITAL SIGNAL PROCESSOR

The core element of N+1 redundancy 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 and D/A timing, P-I compensation low pass filter and current division policy. Figure 6 is the real time analog reference signal and output feedback current with output voltage of close loop control.

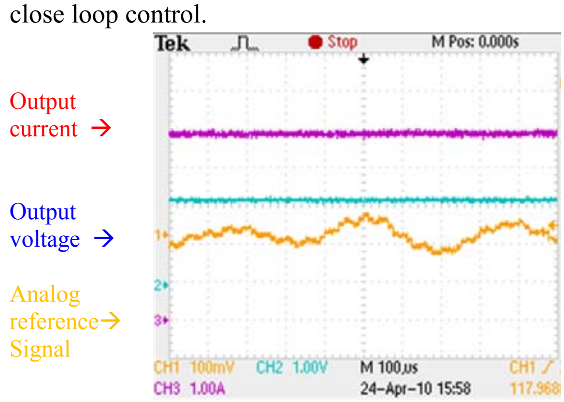


Figure 6: Reference signal and output current with voltage of close loop control.

## EXPERIMENTAL RESULTS

The main feature of this power converter with 8 pieces paralleled MCOR30 is the redundancy function. Figure 7 shows the redundancy function test, one of 8 pieces paralleled MCOR30 is trip-off by a fault event and output current is induced a 30A current drop，the recovery time of output current is 150msec and the voltage drop is 9.8V. Figure 8 shows the input waveform programming, the output current is set with 100A peak-to-peak sine wave，the frequency is 10.232Hz and offset bias current is 60A.

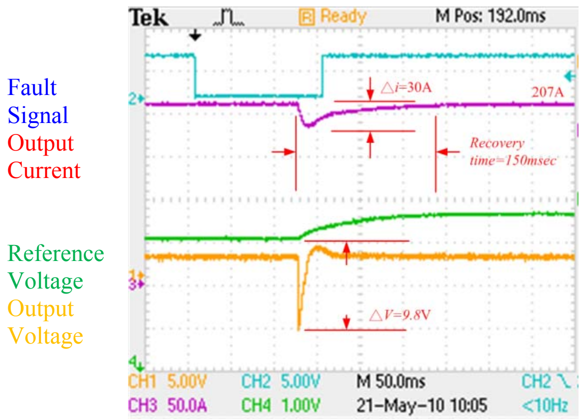


Figure 7: Relation between the fault testing signal and redundancy function.

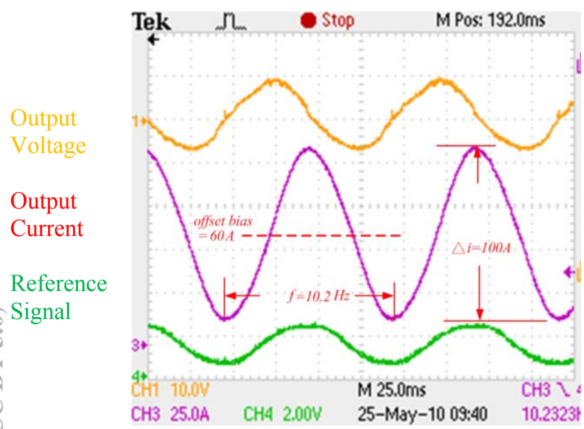


Figure 8: The program input sinusoidal waveform.

The frequency spectrum of output current is measured and demonstrated at figure 9, the ripple current floor is about 30μA (0.1ppm) and the 60Hz ripple is the biggest ripple component that is under 20mA (80ppm).

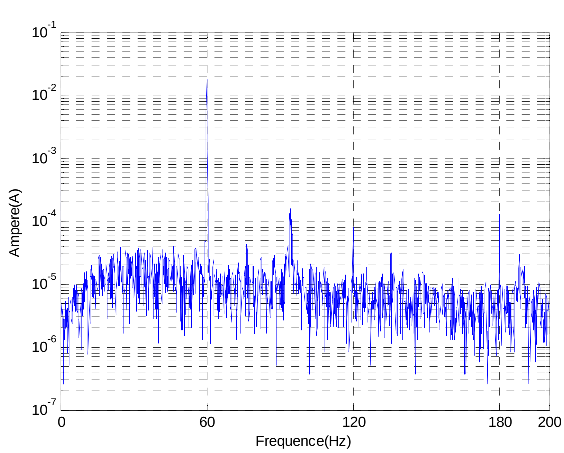


Figure 9: frequency spectrum of output current.

Figure 10 shows the output current stability of the N+1 redundancy power converter with duration of 16 hours, and the stability within ±20ppm.

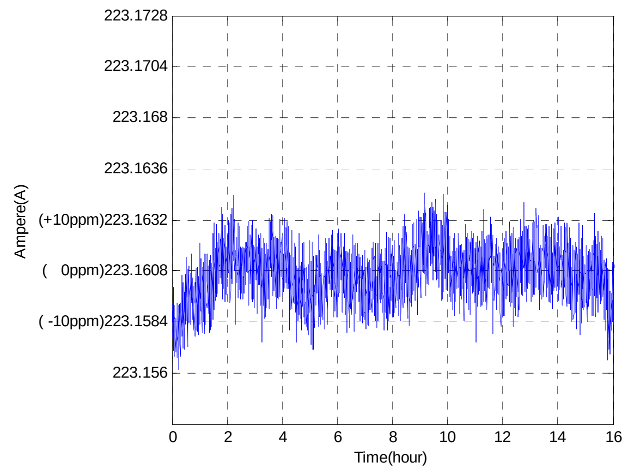


Figure 10: Stability of output current is setting 223.160A.

## CONCLUSION

A DSP is adopted in the digital regulation control circuit to implement the N+1 redundancy power supply system by paralleling 8 current converter modules that could be used as medium power supplies in the TPS. The output current ripple of this N+1 redundancy power supply system is under 5mA, the output current stability is about ±20ppm with testing duration of 16 hours, and the function of N+1 redundancy and programming of output current is operated normally.

This power converter is a prototype that the structure is still necessary to be improved on communication interface, protection circuitry and stable operation for future need in the TPS.

## REFERENCES

[1] William J. Palm III, “MATLAB for Engineering Applications”, McGraw-Hill, Inc, 1999.
[2] TMS320F283xDSP Technical Reference.