10 Hz PULSED POWER CONVERTERS FOR THE ISIS SECOND TARGET STATION (TS-2)

S L Birch, S P Stoneham, ISIS Facility, STFC, RAL, Oxon, OX11 0QX, UK.

Abstract

The Extracted Proton Beamline to the ISIS second target station has two 10 Hz pulsed magnet systems which extract the protons from the existing 50 Hz beamline. Kicker 1 magnet system deflects the beam 12.1 mrad and Kicker 2 magnet system deflects the beam 95 mrad. Both magnets are identical, however each pulsed power converter is considerably different. This paper describes the design requirements, topology, installation, testing and successful operation of both pulsed power converters.

INTRODUCTION

ISIS, Figure 1, sited at the Rutherford Appleton Laboratory (RAL) is one of the world's most intense pulsed neutron sources. Intense bursts of neutrons are produced at 20 ms (50 Hz) intervals when a heavy metal target is bombarded by a high-energy (800 MeV) proton beam from a synchrotron accelerator, releasing neutrons by the process of spallation. Over the past 3 years a second target station (TS-2) has been constructed. TS-2 will provide a 10 Hz beam for up to 18 new instruments. The 10 Hz proton beam is achieved by operating two slow pulsed magnets and a septum magnet to direct the proton beam to TS-2 Extract Proton Beam line (EPB). The TS-2 EPB, which is 149 metres long, will require 56 magnets and their associated power supplies to produce magnetic fields for the beam optics. The power supply ratings range from 1.5 kW to 160 kW with one 680 kW DC septum power supply and the two 10 Hz pulsed power supplies.

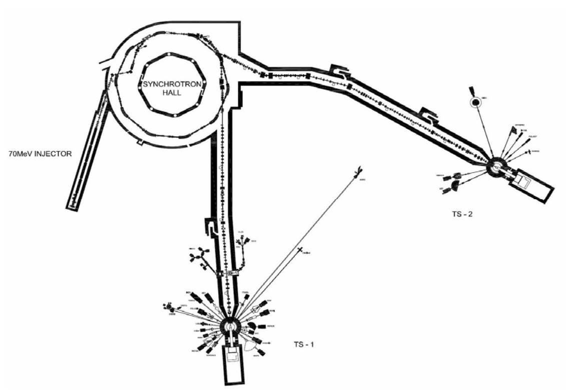

Figure 1: ISIS Layout.

10 Hz PULSED POWER CONVERTERS

The pulsed power converters and two identical kicker magnets were designed and manufactured by Danfysik A/S in Denmark. They provide a half sine-wave current profile with a 12 ms rise time, 600 µs flat top and a 12 mS fall time. The 600 µS flat top will give 100 ppm field stability within each of the kicker magnets. Each power converter is based on a high voltage capacitor bank to drive up the current to the required level (319 A Kicker 1 and 2556 A Kicker 2) and a low voltage capacitor bank to achieve the flat top requirement for a minimum of 600 µS. The stored energy in the magnet is recovered back into the high voltage capacitor bank to reduce the power requirements.

Table 1: 10 Hz Pulsed Power Converter Maximum Ratings.

PSU Type	Power (kW)	Maximum Voltage (V)	Maximum Current (A)
K1 12.1 mrad	2	235	450
K2 90 mrad	30	1355	2800

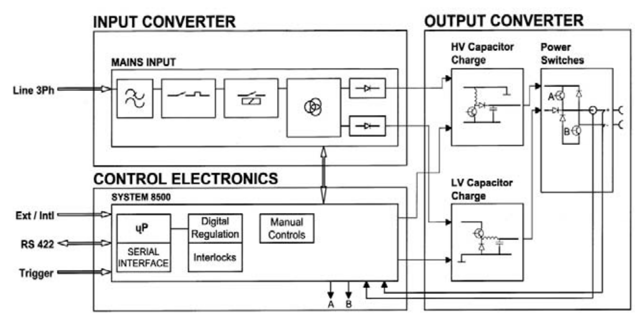

Figure 2: Block diagram of 10 Hz Pulsed Power Converter.

Input Converter.

The AC main input supply is EMI filtered and over current protected with a manually operated circuit breaker. There is two stage switching to minimise the inrush current. A three phase transformer (Delta input, star/delta output) steps down the mains input voltage and provides galvanic isolation.

The transformer output voltage is rectified in a twelve pulse rectifier and filtered with a L-C low pass filter to produce a dc link voltage for the output converter.

Output Converter.

The output converter consists of three major blocks. A high voltage capacitor pre-charger, a low voltage capacitor pre-charger and the power output switches IGBT A and IGBT B (see Figure 2).

Switch Control Principle.

When the capacitors are charged to their predefined values, a ready signal is generated and sent to the regulation loop. A 10 Hz signal from the ISIS analogue waveform system is used to trigger both power converters. When the trigger signal is received both IGBT A and IGBT B are turned on. The flat top period begins after the digitally controlled output current reaches the desired set value, which is 319 A for kicker 1 and 2556 A for kicker 2. IGBT A is then turned off and IGBT B will continue to carry the output current. Figure 3 shows the measured half sine wave current pulses for the kickers. Figure 4 shows the kicker output voltage wave.

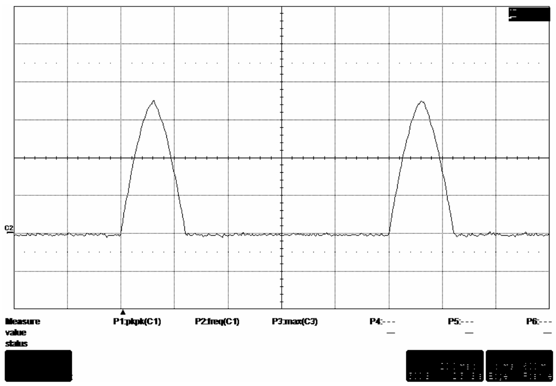

Figure 3: Kicker Measured 10 Hz pulse.

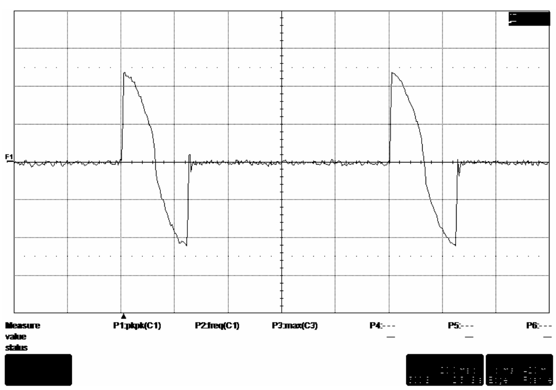

Figure 4: Kicker Measured output voltage.

The flat top for kicker 1 and slope-top for kicker 2 are controlled via a digital feedback loop, the duration being a minimum of 600 μS (see Figure 5 and Figure 6). IGBT B will then open, starting the energy recovery period. In the energy recovery period the current flows back into the HV capacitor through the top diode. As soon as IGBT B is opened the capacitor pre-chargers will also start to re-charge ready for the next pulse.

On Kicker 1 a measure of the flat top accuracy is achieved from the following principle:

dc flat top voltage = resistive load * current.

The voltage across the load inductor will then be zero. No voltage across the inductor is an indication of no change of current.

On kicker 2, in order to maintain the 100 ppm field in the magnet, it was realized that instead of a flattop a small slope was introduced into the wave shape. The slope-top wave shape is maintained by sampling the current value at the beginning and at the end of the flattop, calculating the difference between the two measurements, and adjusting the LV capacitor bank voltage (which affects the slope). The Regulation Module has the option to maintain a specified slope-top instead of a flattop. The slope is now a function of the current instead of a constant as on kicker 1.

slope = a * Iset + b

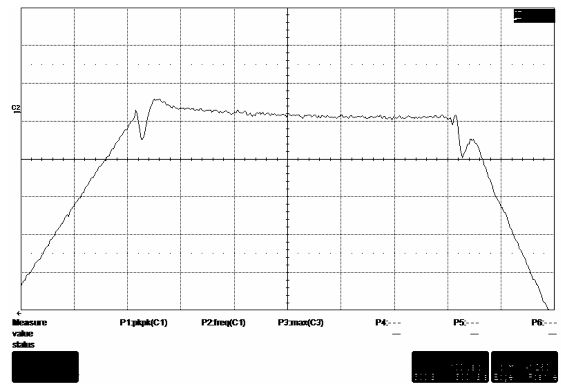

Figure 5: Kicker 1 Measured 10 Hz flat top.

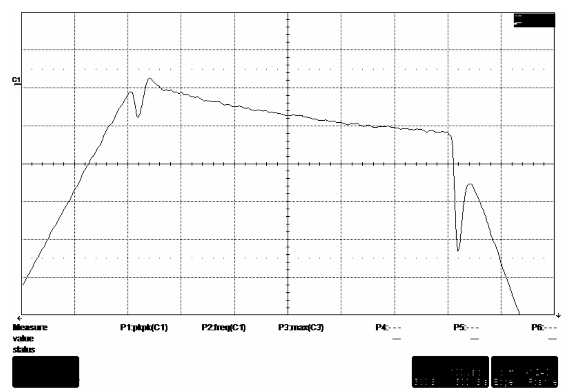

Figure 6: Kicker 2 Measured 10 Hz Slope-top.

High Voltage Capacitor Charger.

The high voltage capacitor charger is a buck/boost converter, boosting the dc link voltage to a value between 50 % and 100 % of the nominal value set by the regulation module. The buck/boost converter is based on the Danfysik 859 series building blocks. The 859 converter is a current mode switch regulator suitable for charging larger capacitor loads. The voltage regulation is manufactured to an accuracy of 0.25 % thus ensuring a rise time jitter of better than ±60 μS. The control module has a fibre optic interface for input and output. The input fibre optic interface is a pulse width modulated (PWM) signal with a fixed frequency. This PWM signal is converted to an analogue 0-10 V voltage level to define the capacitor voltage level. If a pulse is missed the charging converter will be disabled.

The output fibre optic interface has three indication states:

- Continuous off. (module fault, IGBT fault or over load)
- Pulses. (charging in progress)
- Continuous on. (capacitor voltage within specification and ready to be fired)

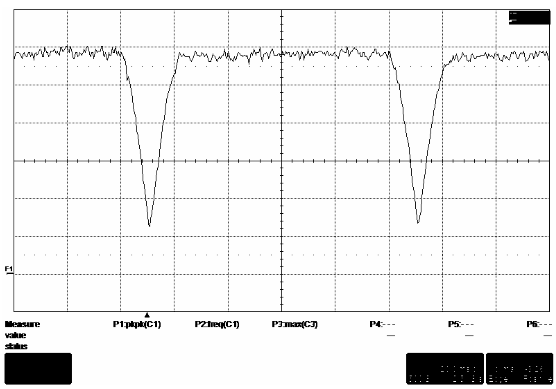

Figure 7: Kicker High voltage capacitor voltage waveform.

Low Voltage Capacitor Charger.

The low voltage capacitor charger is a buck converter controlling the dc link voltage to a value equal to the required voltage at flat top. This is a voltage level given by the regulation module. This voltage is constantly adjusted by the digital loop to an accuracy of 1 %. This equals a flat top deviation of better than 100 ppm.

The control module for the LV capacitor charger works on the same principle as the HV capacitor charger.

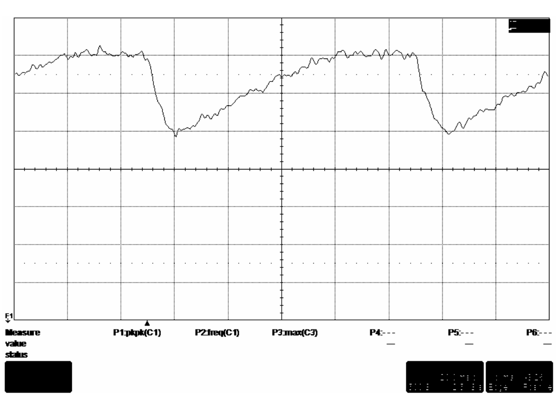

Figure 8: Kicker Low voltage capacitor voltage waveform.

Control Electronics.

The control electronics perform the following tasks:-

- Control of the input converter block
- Control of the output converter block
- Communication; remote & local
- Current measurement and regulation control
- Status and monitoring
- Interlocks; internal & external

Output Cables.

As the kicker 2 pulse is running at a level of 2556 A the mechanical forces on the output cables are considerable. The standard idea of running two single core cables close together would result in a mechanical force of 74 N/m (7.55 kg/m). A 4-core aluminium strip armoured cable has been used, with the positive and negative cores being diagonally opposite each other, to reduce forces (see Figure 9). Whilst the inductance increased a small amount the forces were greatly reduced to 12.4 N/m (1.26 kg/m). The aluminium cables (approximately 30 metres long) were run at high level to interlocked transition boxes close to the magnets and converters. Soft flexible cables were then taken from the transition boxes to the magnets and to the converters.

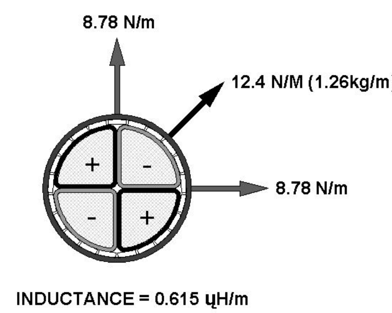

Figure 9: Output cable profile.

Installation.

After exhaustive factory acceptance tests of the kicker systems at Danfysik, the kicker power converters were installed into the ISIS R6 power supply hall and the magnets into the extracted proton beamline in August 2007. They were first run and tested in November 2007 and a proton beam was successfully extracted using the kicker power converters and magnets on 14th December 2007.

ACKNOWLEDGMENTS

We would like to thank P. A. Elkjær and C. Nielsen of Danfysik A/S. Jyllinge, Denmark for providing information on the design and manufacture of the pulsed power converters and P.G Barnes of ISIS for providing all measured data.